INFLUENCE OF BARRIER SEPARATED HOV LANE ACCESS LOCATIONS ON HOUSTON HOV LANE UTILIZATION

A Thesis

by

KEVIN LIPNICKY

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2008

Major Subject: Civil Engineering

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Approved by:

Chair of Committee,	Mark W. Burris
Committee Members,	Luca Quadrifoglio
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ABSTRACT

Influence of Barrier Separated HOV Lane Access Locations on Houston HOV Lane Utilization. (May 2008)

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High Occupancy Vehicle (HOV) lanes are employed in many cities as a traffic congestion mitigation technique. These lanes are intended to provide a travel time benefit to carpools and buses, thus providing an incentive to form carpools or take transit. The time and frustration involved in finding and using HOV lane access points may act as a deterrent to HOV lane use. Thus, proper planning of HOV lane access may be able to improve convenience for potential users, increasing HOV lane utilization.

By optimizing HOV lane volumes, high levels of service and trip reliability are ensured for those who carpool. Congestion is also reduced on General Purpose Lanes (GPLs) due to the diverted traffic. Public approval is tied to HOV lane utilization, which may be affected by access. Thus, HOV lane success may be determined in part by accessibility.

This research investigated the possible relationship between the time required to access the HOV lane and travelers' choice of HOV lane as their mode. Additionally, the distance to HOV lane access points and the type of access point used were examined for their influence on HOV lane use rates. It was concluded that neither the type of HOV lane access point, nor the added time necessary to access the HOV lane were significant factors in HOV lane use rates. Instead, the convenience of carpool formation and the convenience of HOV lane access to traveler's origins and destinations were found to be the most important factors in HOV lane use rates. Specifically, the HOV lane use rate

for the area 5 to 7 miles from the nearest HOV lane exit, which includes Downtown Houston, was much higher than the use rates for any other area.

DEDICATION

To my wife Sarah. Your support, assistance, and your patience with me have made this, and most of the things I have accomplished in the past few years, possible. I continue to hope that over my lifetime I can repay you for your kindness, caring, and dedication.

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1. INTRODUCTION

1.1. Background

High Occupancy Vehicle (HOV) lanes have been successfully used as a congestion mitigation technique in several metropolitan areas in the United States (*1*). These lanes have provided rapid movement for high numbers of person-trips during daily commutes, and have encouraged greater carpooling in many communities even as nationwide vehicle occupancy is on the decline (*2*, *3*). This said, the public perception of HOV lanes tends to be that they are underutilized, and that the capacity they provide should be converted to use for all vehicle classes. This attitude has been best demonstrated in New Jersey on Interstates 80 and 287. There, discontinuous portions of a suburban HOV system were built and opened to traffic. However, the lack of a comprehensive transit system in the area, coupled with the omission of direct connections between the HOV lanes on the two routes lead to limited utilization of the lanes. Public outcry for the redesignation of the lanes to General Purpose Lanes (GPLs) resulted, which occurred in 1998 (*4*).

Underutilization was noticed early in the development of the HOV lane system in Houston. Originally, these lanes were built by the transit agency to facilitate express bus service on congested corridors. As such, they are separated by a barrier from the GPLs, except at specific access points. However, it was realized that by only allowing buses and authorized vanpools on the lane, the majority of the capacity was wasted. Thus, in Houston's HOV lanes were opened to carpools, greatly increasing their utilization (*5*).

Despite the relaxation in occupancy requirements in Houston, HOV lanes are still underutilized most of the day. Factors influencing this include the fact that carpooling can be inconvenient, and that the travel time savings and reliability offered by the HOV lane does not outweigh the inconvenience of carpooling for many travelers. The convenience of HOV lane access points may play a role in HOV lane utilization. In fact, several factors have been indicated as being important influences on HOV mode choice, including accessibility of HOV facilities, travel time savings, and the availability of

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This thesis follows the style and format of the *Transportation Research Record.*

transit to travelers. The unanswered question is how important a factor HOV lane accessibility is on HOV lane utilization.

1.2. Problem Statement

Despite the research done in the area of HOV and High Occupancy/Toll (HOT) lanes, little is known about the influence of access locations on lane utilization. Understanding the interaction between the roadway network where HOV or HOT lanes are located and the optimal locations for access to these lanes is critical to maximizing the potential of these expensive infrastructure improvements. Efficient access locations are important for HOV lane operation, since access points must compliment and facilitate express bus service in order to maximize the benefit of the lane. Access is also important for HOT lanes, where customers paying to use the lane will only do so if the HOT lane is an attractive alternative to congested General Purpose Lanes (GPLs).

The problem of access is multifaceted, particularly when the lane is barrier-separated from the GPLs. The number of access points must be limited to as few as practical in order to maximize the travel time savings on the HOV or HOT lane. However, access points spaced too infrequently could eliminate the travel time benefit of the HOV or HOT lane by requiring travelers to deviate from their shortest time path to a longer and less convenient route.

Optimal access locations are not always obvious when carpools are considered, let alone Single Occupant Vehicle (SOV) buy-in. These travelers originate from, and travel to, a much wider array of locations, complicating the access location question. Considering the cost involved with HOV and HOT lane construction, it is critical to understand how to minimize the overall total travel time for potential users of the lanes. This will provide the greatest benefit to all roadway users, and reduce the chances of public backlash due to perceptions of an underutilized HOV lane.

1.3. Research Objectives

The goal of this research was to investigate the effects of HOV lane access on HOV lane use. The specific objectives included:

- Determine HOV lane use rates by proximity of origins and destinations to access points
- Determine HOV lane use rates by the difference between HOV lane access time and General Purpose Lane (GPL) access time (added HOV lane access time) for people's routes
- Determine HOV use rates by the ratio of added HOV lane access time to total trip time
- Determine how HOV lane access type affects HOV lane use rates

This research, by exploring factors not well understood to transportation researchers and practitioners, enhances the understanding of factors affecting travelers' choice to use HOV lanes, and thus could allow professionals to implement designs which encourage greater HOV lane use.

1.4. Organization

This thesis is organized into five primary sections. Section 1 introduces HOV and HOT lane access issues, explains the research problem, and indicates the objectives of the research. Section 2 reviews pertinent literature about HOV and HOT lane utilization, HOV lane access, and factors affecting the choice to carpool or use transit. Section 3 indicates the sources of data used in the analysis, such as surveys, GIS files, and travel time data, and explains how this data was adapted to the purposes of this study. Section 4 details the steps used in the analysis, as well as the results and discussion. The conclusions are provided in Section 5.

2. LITERATURE REVIEW

2.1. Introduction to HOV and HOT Lanes

The first HOV lane was implemented in 1969 on Virginia's Shirley Highway, Interstate 395. While this was originally an express busway, vanpools and carpools with four or more passengers were allowed beginning in 1973. This and other early HOV lanes originated in the United States partially as a response to escalating congestion, as well as the fuel crises of the 1970s. From that time, HOV lane mileage has grown to 1300 lane-miles in 1995, and 3100 lane-miles in 2005 (*6*).

In spite of the rapidly growing amount of HOV lanes in the United States, carpooling is decreasing nationwide. Between 1993 and 2003, carpooling declined 15 percent nationwide, while total vehicle miles traveled increased 25 percent. That said, while carpooling has declined 30 percent overall over the past 20 years, carpooling on corridors with HOV lanes has increased more than 100 percent over the same period (*6*). Even accounting for the increased HOV lane-mileage, this implies that HOV lanes are successful at encouraging the formation of new carpools.

HOV lanes are used to encourage greater levels of carpooling and to enhance the attractiveness of the transit mode. This is accomplished by offering travel time savings over congested GPLs. For some travelers, the travel time savings offered by the HOV lane is sufficient to offset the inconvenience of forming a carpool or traveling by transit. Increased carpooling allows a greater number of person-movements to be made in a corridor, reducing the corridor's congestion, fuel consumption, and on-road mobile-source emissions, while enhancing mobility as compared to a corridor with fewer carpoolers.

Other enticements to carpool include ride-matching services and employer-based carpooling incentives. These techniques increase the convenience of carpooling, making it a more attractive mode for some travelers. Carpool incentive programs are generally inexpensive, and although each incentive program generally has a small effect on carpool formation, these programs are generally seen as more effective than infrastructure implementation. However, a strong synergistic effect exists between carpool incentive programs and infrastructure improvements such as HOV lane implementation and park-and-ride facilities (*6*). Thus, a comprehensive trip reduction program should include both carpooling incentive programs and HOV infrastructure.

One technique proposed to increase utilization of HOV lanes and decrease travel time for Single Occupant Vehicles (SOVs) is High Occupancy/Toll (HOT) and managed lanes. These lanes have the potential to combine the demand management benefit of encouraging and facilitating high occupancy vehicles with demand management through pricing of SOVs (*3*). Pricing would be used to regulate the number of SOVs using the lane such that total HOT lane traffic remains free-flow. This optimizes utilization of the lane, providing a near free-flow speed trip to more vehicles than the HOV lane.

2.2. Reasons for Choosing to Use an HOV or HOT Lane

Several factors are known to affect HOV lane mode choice, including accessibility, travel time savings offered, and transit availability (*7*, *8*). Aronson and Homburger manually linked carpool and transit users' origins and destinations, and used the survey respondents' reported travel time, distance, and cost savings to determine the benefits of park-and-rides in the San Francisco and Los Angeles areas. Additionally, they identified many factors affecting park-and-ride lot utilization and resulting carpool and transit use. Foremost, they indicated that accessibility was important to park-and-ride lot use, and that convenience was more important in the morning peak direction than it was in the evening. Accessibility was important, they noted, due to the need to minimize the delay users incurred to maximize utilization. Other factors included the population within five miles of the park and ride, and the visibility of the park-and-ride from SOV routes. Visibility was indicated as a factor in attracting new park-and-ride users.

The researchers found that the benefits of a park-and-ride lot became substantial at distances from the trip attractor of 20 or more miles, and transit center benefits became substantial at distances of 10 or more miles. They also noted that park-and-rides were not as important in encouraging carpooling for very long trip distances, as the benefits of carpooling were already great enough to encourage the behavior without external incentives. Additionally, they found no strong correlation between increased carpooling or the associated decrease in vehicle miles traveled and the location or design of the park-and-ride (*7*). This finding can be extended to HOV lane access points in the Houston area, because many are located within park-and-ride lots or transit centers. However, it contrasts with our understanding of mode choice behavior, which would imply that a well placed park-and-ride, which minimized the time a commuter deviated from their standard route to access it, would have greater use than one which was less accessible.

Kumar and Goss indicated that travelers would be more likely to take transit when parking costs at their destination were high, and when transit was free. Additional factors indicated included the traveler's availability of an automobile, and the accessibility of the bus stop. They indicated that when bus stops were within a quarter mile of the origin and destination, and headways were in the 5 to 10 minute range, that transit mode share would reach as high as 50 percent (*8*). Notable in this study was the indication that accessibility was a major factor in choosing a mode, other than driving alone. Based on the factors described by Aronson and Homburger, it is reasonable to expect that this extends to HOV lane mode choice.

Aronson and Homburger's (*7*) assertion that the effect of the location of park-and-rides has little effect on utilization is supported by Hall (*9*). Hall's study focused on the effect of the spacing of highways and arterials on relative use and vehicle miles traveled using a theoretical framework of minimizing net travel time. The study showed that frequently spaced but lower capacity roadways could reduce overall network travel when compared to infrequent but very high capacity roadways due to the reduced need for backtracking. In addition to this, the study found that the frequency of entrance and exit spacing had little effect on highway travel. Even with a doubling of the highway access spacing, only 10 to 20 percent of travel shifted to parallel arterials. Furthermore, the study found that express highways with infrequent access would likely be able to attract 50 percent or more or highway travel (*9*). This demonstrates that frequent access to an express route is not necessary. These findings can logically be extended to HOV lanes, which function similarly to express highways for HOVs due to their access and occupancy restrictions.

Hall's findings support Aronson and Homburger, who indicated that park-and-ride location was unimportant in park-and-ride use and carpool mode choice. At the same time, Kumar and Goss agree with Aronson and Homburger that a sizeable population in close proximity to a park-and-ride or transit facility is important to the success of the facility, and that accessibility is very important to the success of the facility. However, none of this demonstrates what HOV accessibility actually means, or the spatial or travel time distribution of HOV mode choice with respect to the location of access points.

2.3. HOV and HOT Lanes in Houston

Some of the most successful HOV lanes were originally designed as transitways, with carpools being allowed after construction of the lane. This was the case with the I-45 North Freeway and I-10 Katy Freeway HOV lanes in Houston, Texas (*10*). In August 1979, the I-45 North Freeway contraflow bus lane began operation. This lane was operated by taking the innermost lane in the off-peak direction and partitioning it from opposing traffic with pylons. Due to the lack of physical protection between opposing traffic and contraflow traffic, only specifically permitted busses and vanpools with specially trained drivers were allowed to operate in the contraflow lane (*5*).

Despite low vehicular volumes, the contraflow bus lane project was highly successful, moving nearly as many people in the HOV lane as in the adjacent two lanes. This success lead to plans to install permanent, reversible, barrier separated HOV lanes on Houston's most congested roads. The lanes were designed with efficient bus routes in mind, and as a result access points tend to be few and widely spaced on Houston's barrier separated HOV lanes. Houston's first barrier-separated HOV lane opened in conjunction with the completion of a reconstruction project on the North Freeway in September 1984. This also marked the end of the North Freeway contraflow lane.

Shortly thereafter, in October 1984, the Katy Freeway HOV lane opened. The I-10 Katy Freeway HOV lane consists of a 13.3 mile long, reversible, barrier-separated facility between I-610 and SH-6, along with a buffer-separated concurrent-flow lane in each direction between SH-6 and Mason Road in the Houston suburb Katy, Texas. There are two intermediate access points to the barrier-separated portion of the HOV lane, one near the SH-6 terminus, and one near the mid-point of the facility. As of 2003, this HOV lane operates at an occupancy of approximately 3.22 persons per vehicle, while the adjacent GPLs carry roughly 1.12 persons per vehicle (*5*). The current extent of the Houston HOV lane system is shown in Figure 2.1.

Implementation of this project was accelerated to coincide with pavement rehabilitation programmed for the corridor. As this HOV lane was designed and planned as a direct follow-up to the North Freeway contraflow lane, both the North and Katy Freeway HOV lanes opened with a bus and vanpool only restriction. This lead to extremely low utilization of the Katy HOV lane. Gradually, occupancy requirements were relaxed in 1985 and 1986 to allow 2+ carpools, leading to increased vehicular volumes on the HOV lanes. However, after less than a year and a half of HOV 2+ operation, peak volumes on the Katy Freeway HOV lane began to exceed 1500 vehicles per hour, leading to degradation of trip reliability and travel time savings. Thus, in October 1988, the occupancy restriction on the Katy Freeway HOV lane reverted to 3+ during the peak periods (*5*).

FIGURE 2.1 Houston HOV Lane System Map. HOV Lanes shown in red (*11*)

Increasing the occupancy restriction on the Katy Freeway during peak periods had the desired effect of returning travel speeds to free-flow, and improving trip reliability. However, substantial unused capacity resulted. The QuickRide program, which began in January 1998, seeks to address that issue. This project allows vehicles with two occupants to utilize the Katy HOV lane during the 3+ restriction period for a $2 fee per trip. QuickRide has been able to attract two person carpools from the GPLs to the HOV lane when they would otherwise be restricted, improving trip reliability and travel time for those travelers without adversely impacting HOV lane operations.

Due to the success of the Katy Freeway QuickRide experience, this HOT lane program has been expanded to the US-290 Northwest Freeway during the morning peak period (*12*). However, QuickRide participation is much lower than anticipated, and demand is still less than capacity on the HOV lanes during the peak period. The reasons for this are unclear, but may include the inconvenience of forming a permanent two-person carpool, that forming a 3+ carpool once a 2 person has been formed is not as difficult, and that motorists are simply unaware of the program (*13*). It is also possible that those who do not currently carpool are unwilling to use the HOV lanes due to difficult access to the lane. In the case where a traveler's access to the HOV lanes is difficult, there would exist two disincentives to carpooling, first, the difficulty and time necessary to form the carpool, then the difficulty and time necessary to access the HOV lane.

2.4. The Challenge of HOV Lane Underutilization

The public sometimes perceives HOV lanes to be underutilized, and that the capacity they provide should be converted to use for all vehicle classes. This attitude has been best demonstrated in New Jersey on Interstates 80 and 287. There, discontinuous portions of a suburban HOV system were built and opened to traffic. However, the lack of a comprehensive transit system in the area, coupled with the omission of direct connections between the HOV lanes on the two routes lead to limited utilization of the lanes. Public outcry for the redesignation of the lanes to General Purpose Lanes (GPLs) resulted, which occurred in 1998 (*4*).

HOV Lane underutilization is not merely a public relations problem. Any lane carrying less traffic than theoretically possible not only operates less efficiently than it is capable of, but also contributes to less efficient operation of other lanes on the road. In other words, when an HOV lane is underutilized, the HOV lane offers fewer benefits, and adjacent GPLs offer higher costs, than a system with an HOV lane operating at capacity. This, of course, is counter to the purpose of HOV lanes, which is to optimize person-trip capacity of a highway corridor.

2.5. Reasons for HOV Lane Underutilization

HOV Lane underutilization occurs as a result of many factors. Principal among these are that the benefits of travel time savings and trip reliability do not outweigh:

- The inconvenience of carpooling
- The additional travel time necessary to form a carpool
- The difficulty in accessing the HOV lane for enough travelers to fill the lane to capacity

Transit agencies employ strategies such as carpool matching services and the construction of park-and-ride and park-and-pool stations to reduce carpool formation time and carpool disutility (*6*). However, the impacts of HOV lane access difficulties are not as well understood.

Underutilization can be explained graphically. Figure 2.2 shows the typical change in HOV lane utilization by vehicle occupancy and relative volume. In early years, demand for the HOV lane is typically low, and is thus underutilized. However, over time, volumes on the HOV lane increase, and underutilization decreases. Eventually, volumes reach a point where either congestion occurs on the HOV lane, reducing its ability to encourage new carpool formation and transit use, or occupancy restrictions are increased. When the occupancy restriction is increased, free-flow speeds and travel time savings over the GPLs are maintained, but utilization is dramatically reduced (*14*). This implies that high levels of vehicular utilization are difficult to attain on HOV lanes, as periods of “good” utilization give way to congestion and reduced levels of service.

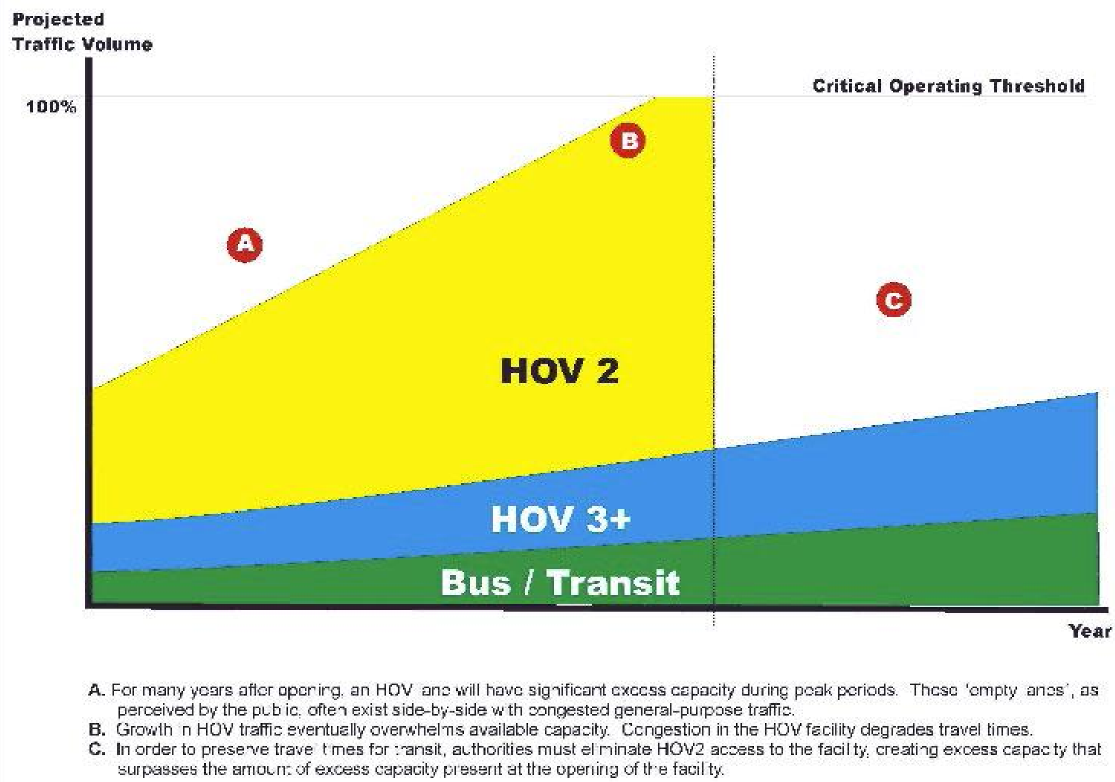

FIGURE 2.2 Typical HOV Lane Utilization Over Time (*14*)

As Swisher, et al. indicate, one technique for minimizing underutilization is converting HOV lanes to managed lanes. These lanes give priority to transit and HOV modes, while permitting lower occupancy modes in a way which optimizes utilization without impacting travel speeds for transit vehicles and HOVs. Several management strategies exist, including:

- Varying the groups of vehicles, such as SOVs, Inherently Low Emissions Vehicles (ILEVs), or trucks, which are eligible to use the lane.
- Time-of-day vehicle group eligibility
- Pricing
- Physical control, such as barrier-separation

- Operational control, such as reversible lanes

Proper use and variation of these techniques can minimize HOV lane underutilization without negatively impacting HOVs and transit vehicles (*14*). One aspect of physical management that is not emphasized in Swisher et al. is optimizing the location, type, and number of access points on an HOV corridor. This may be due to limited understanding of the effect HOV lane access has on HOV and transit mode choice, and thus HOV lane utilization.

2.5.1. The Benefits of Barrier Separation

Barrier-separated HOV lanes have the advantage of increasing the safety of the HOV lane by eliminating the possibility of a slower-moving vehicle from the GPLs entering the HOV lane, a well known safety issue for buffer-separated HOV lanes (*15*). Barriers also reduce the number of speed reductions which occur due to weaving at entry and exit points, which tends to be a substantial problem on Houston's GPLs.

Observations in Houston, Dallas, and Minneapolis found that 7 percent of overall maneuvers occurring in the access openings of buffer-separated HOV lanes were for passing, either slower moving GPLs using the HOV lane as a passing lane, or vehicles from the HOV lane moving into the GPLs to pass slower moving HOVs. Neither of these types of maneuver are desirable (*16*).

Travelers in Dallas, Texas were observed entering a buffer-separated HOV lane from an access point which ended 1250 feet upstream of the ramp those travelers used to access the freeway. Twenty-five percent of the travelers making this maneuver, which required crossing four freeway mainlanes, entered the HOV lane late, after the access point ended. This implies both that if a maneuver is physically possible, that some drivers will attempt it, and that those drivers who do attempt such maneuvers accept very small or no margins for error, making their maneuvers less safe than desirable (*17*). This helps explain why crash rates are generally higher for buffer-separated HOV lanes than for barrier-separated HOV lanes.

2.5.2. Potential Negative Access Issues with Barrier Separation

The main objective of HOV lanes is to increase person movement and reduce congestion by encouraging transit use and carpooling through the benefit of travel time savings to HOVs (*2*). As such, access is focused on transit centers, park-and-ride stations, and major bus stops. However, these sorts of HOV lane access points can require substantial travel time to access and traverse.

Difficult, time consuming access, coupled with the increased time necessary to take transit or form a carpool reduces the incentive for commuters to shift mode from SOV to higher occupancy modes. This becomes especially true as the time necessary to form a carpool and to access HOV lanes becomes close to, or greater than, the travel time savings afforded by the HOV lane. Thus, access to the HOV lane which requires substantial deviation from the minimum time path for a traveler is counter to the objective of an HOV lane.

2.5.3. The Need to Examine the Potential Impact of Barrier Separated HOV Lane Access

Simulations conducted by the Texas Transportation Institute for barrier-separated managed lane (ML) facilities have concluded that closely spaced access points from local streets to freeways and freeways to managed lanes cause substantial operational difficulties and low GPL speeds due to the amount of cross-freeway weaving necessary to go from the right to left side of the freeway GPLs (*18*). However, the authors stressed that their conclusions were general in nature, and that simulations of projected conditions in proposed managed lane systems would be necessary to accurately determine local needs. Most importantly, their research did not explore the interactions between roadway traveler characteristics and freeway and managed lane access points. Their research assumed 4 entry and exit volumes as a portion of total traffic at the corridor access points, 4 initial roadway volumes, and 4 weaving volume portions for traffic accessing the managed lane at the next entrance downstream of their freeway entrance, or exiting at the next freeway exit downstream of their managed lane exit.

This was useful for their goal of providing recommendations for what volume levels to consider direct connections between side streets or service roads and the managed lanes. This does not indicate, however, where these access points should best be placed with relation to traveler needs, or what impact these access points may have on lane use.

Many HOV and HOT lane planners, designers, and operators understand that proper placement of lane ingress and egress points is important. For example, in reference to the importance of before and after examinations of HOV projects, it is stated:

> *The information collected as part of the evaluation process has value for operating decisions relating to the HOV facility…. Monitoring these and other aspects of the HOV lane as part of the evaluation process can identify problems that may need to be addressed. For example, changes in operating hours, vehicle occupancy requirements, bus service levels, and access/egress points may be necessary. Thus, the data provided from before-and-after studies, especially longitudinal data on the use of the facility, serves a critical operations function. (19)*

This clearly indicates the importance that HOV and HOT lane access location can have. Changing HOV lane access locations is relatively straightforward and not prohibitively costly for buffer-separated lanes. However, the best safety and travel time savings characteristics are found on barrier-separated lanes. Rigid barriers, limited right of way, and high construction costs make altering access locations on barrier-separated HOV lanes after construction prohibitive. As such, it is necessary to properly locate access points in the design phase of barrier-separated HOV and HOT lanes. Thus, designers must have an understanding of how access location affects HOV or HOT lane performance in order to properly place and implement access to the lanes in question.

3. DATA COLLECTION AND REDUCTION

In this section, the data which was collected in order to examine the effect of HOV lane access is described. Surveys were conducted, the results of which indicated origin and destination location, mode choice, time of day of travel, and socioeconomic characteristics. The travel times to use HOV lane ramps were collected, along with the type of ramp. Data was then reduced to include only travelers whose commutes were shown to be in the peak direction. Because the HOV lanes only operated in the peak direction, only those travelers may have used the HOV lane.

Several different surveys have been used to gauge various aspects of HOV and HOT lane use in the Houston and Dallas areas in the past few years. These surveys were originally targeted at different audiences, examining many similar travel characteristics. Two of these surveys were combined for use in this analysis, and are described in Section 3.1.

3.1. Data Collection

3.1.1. Surveys

One of the surveys used for this research was administered to a wide array of travelers on the Katy and Northwest Freeways in the Houston area. Traveler groups included transit users, casual carpoolers, freeway mainlane travelers, and HOV lane travelers. This survey was administered primarily to determine respondent reactions to various HOT lane pricing and occupancy scenarios (*20*). This survey is included in the Appendix under the name Houston HOT Lane Corridor Travel Survey. Surveys were mailed to freeway mainlane and HOV lane travelers. To determine where to mail surveys to reach the target user groups, video cameras were placed along the Katy and Northwest Freeway corridors to record the license plate numbers of travelers along those roadways. In 75 hours of video, 19,260 readable license plates were observed. After removing plates registered to businesses, duplicates, plates with no address on file with the Texas Department of Public Safety, and plates from states other than Texas, approximately 14,000 travelers in the corridors of interest were identified, and surveys were mailed to their addresses.

Surveys of transit users were conducted by having surveyors distribute the surveys on-board buses. Respondents were allowed to return the surveys directly to the on-board surveyors, or via a postage-paid return envelope. Likewise, surveys were distributed to casual carpoolers as they stood in the "slug lines", and were allowed to return their surveys via postage paid envelope (*21*). Additionally, all respondents had the option of completing the survey online. The number of surveys administered to each target group, the number of surveys returned, and the response rate is shown in Table 3.1 below.

TABLE 3.1 Houston HOT Lane Corridor Travel Survey Response Rates (*20, 21, 22*)

Target Market	Approximate # commuters in Target Market	Surveys Distributed	Surveys Returned (Mail)	Surveys Returned (Web)	Total Response Rate
GPLs	35,500	8,670	1,441	680	24.4%
HOV lane (non-QuickRide)	13,500	5,330	490	94	11.0%
Transit	5,350	700	546	38	83.4%
Casual Carpool	580	540	200	16	40.0%
Total	54,930	15240	2677	828	23.0%

The other survey used was administered primarily online to travelers in both Houston and Dallas, Texas. This survey focused on the characteristics of respondents' trips, socioeconomic characteristics of respondents, respondents' attitudes toward the concept of managed lanes, and their reactions to different toll and occupancy scenarios for managed lanes. This survey is included in the Appendix in the section entitled Managed Lane Survey.

Several techniques were used to advertise this survey, and several methods of response were allowed. One of the most successful methods of advertisement was placing links to the survey on transportation related websites, such as the North Texas Tollway Authority and Harris County Toll Road Authority sites. Additional methods of advertisement included push cards given at toll booths, newspaper articles, television news stories, and e-mails from employers to their employees (*23*).

While the online survey provided a sizeable sample, certain groups were underrepresented in the sample, especially low income African-Americans and Hispanics. To increase the response rate from these groups, laptop computer and paper surveys were administered at Department of Public Safety drivers' license offices in areas with high levels of the target socioeconomic groups, as well as libraries and a community center in Houston (*23*). The number of respondents using each method of response is shown in Table 3.2.

TABLE 3.2 Responses to Managed Lane Survey by Survey Method

Survey Type	Dallas	Houston	Total
Web Based (Online)	1852	2405	4257
Laptop survey	49	85	134
Paper	135	85	220
Total	2036	2575	4611**
**Location of 46 surveys was unknown and 23 surveys were duplicates. Therefore, total number of surveys was 4611+46-23=4634			

For the purposes of this research, the responses from Dallas were not included. Only those respondents who used either the Katy or Northwest Freeways were examined in this research. Of the total respondents to the Managed Lane survey, 1001 reported using the Katy or Northwest Freeways. Thus both surveys targeted travelers on those two specific corridors. Many of the questions asked, especially regarding socioeconomic characteristics, commute characteristics, and the rationale behind traveler mode choice, were similar in both surveys. This information is the focus of this research, and was combined, substantially increasing the amount of data available.

3.1.2. Complicated HOV Lane Access

Access to the HOV lanes is complicated and time consuming at many points. While slip ramps allow direct access between freeway mainlanes to the HOV lane (primarily at the ends of the HOV lane), neighborhood oriented access through park-and-ride and transit facilities takes far longer to use, as shown in Table 3.3. Furthermore, these access points may require substantial route deviation for travelers. Schematics and images of the access points on the Northwest and Katy freeways are used to explore the nature of some of the more difficult access points. Figure 3.1 is the schematic for the Northwest Transit Station Park-and-Ride (Number 6 in the figure on page 28).

This HOV lane access point is located near the slip ramp northwest of West Road. However, there is no direct access between this access point and the eastbound GPLs. For travelers to use this park-and-ride facility from locations further northwest, they must exit, pass through four signals, and travel more than a mile and a quarter from the GPL exit to the time they enter the HOV lane. This process takes approximately 2.75 minutes, not accounting for the time necessary to pick up carpool partners or to park and join a carpool. Furthermore, the location and orientation of different driveways for buses, HOVs, and SOVs entering and exiting the facility make navigation difficult, as shown in Figure 3.2. While this access point may be convenient for the neighborhood it is located in, it is quite inconvenient for travelers in more remote suburbs.

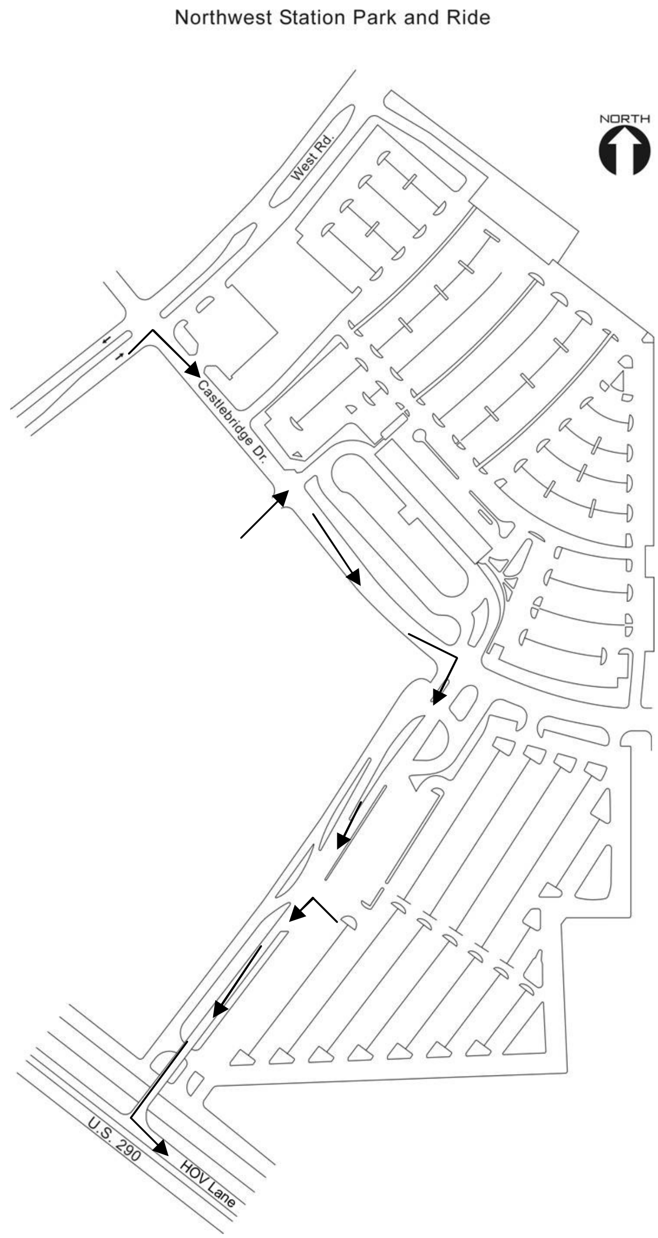

FIGURE 3.1 Schematic Map of the Northwest Transit Station Park-and-Ride (*24*)

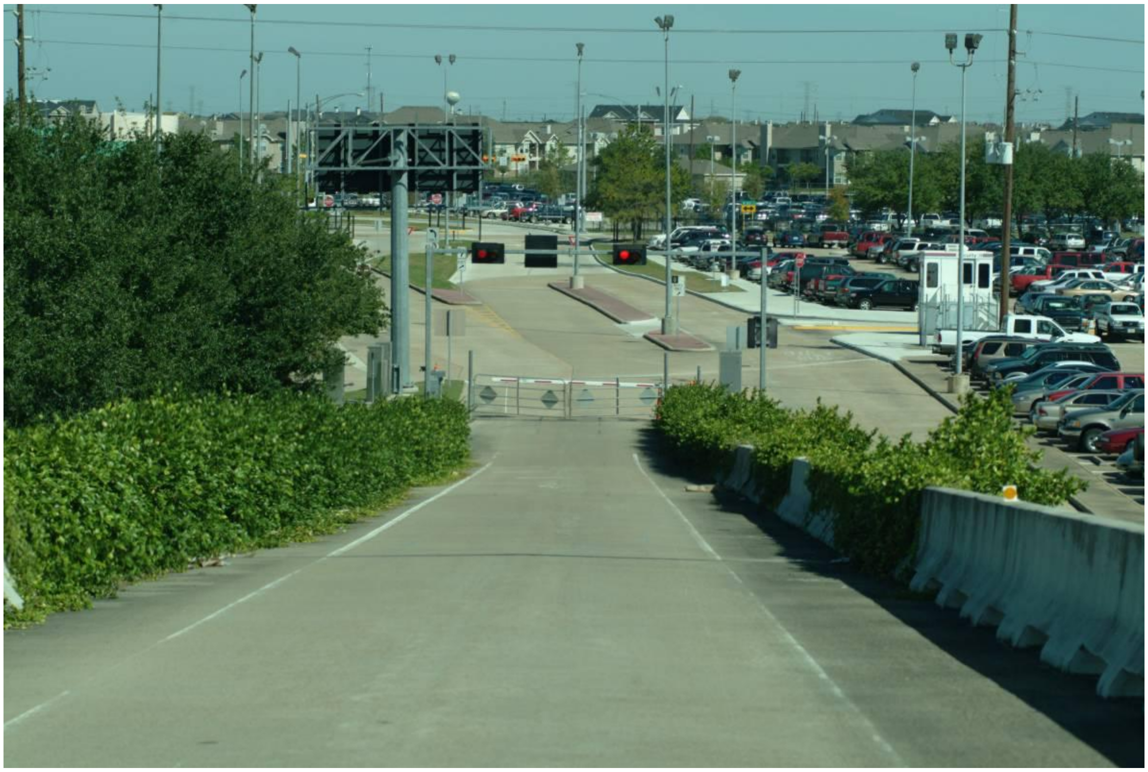

FIGURE 3.2 HOV Access Ramp Entering Northwest Transit Station

The next access point traveling toward downtown is the West Little York Road Park-and-Ride. This access point is located northwest of the intersection of West Little York Road and Hempstead Highway, as shown by Number 5 in the figure on page 28. Travel from this intersection to the HOV lane takes just over 2 minutes, and requires passing through the signal at West Little York and Hempstead Highway. This access is illustrated in Figure 3.3.

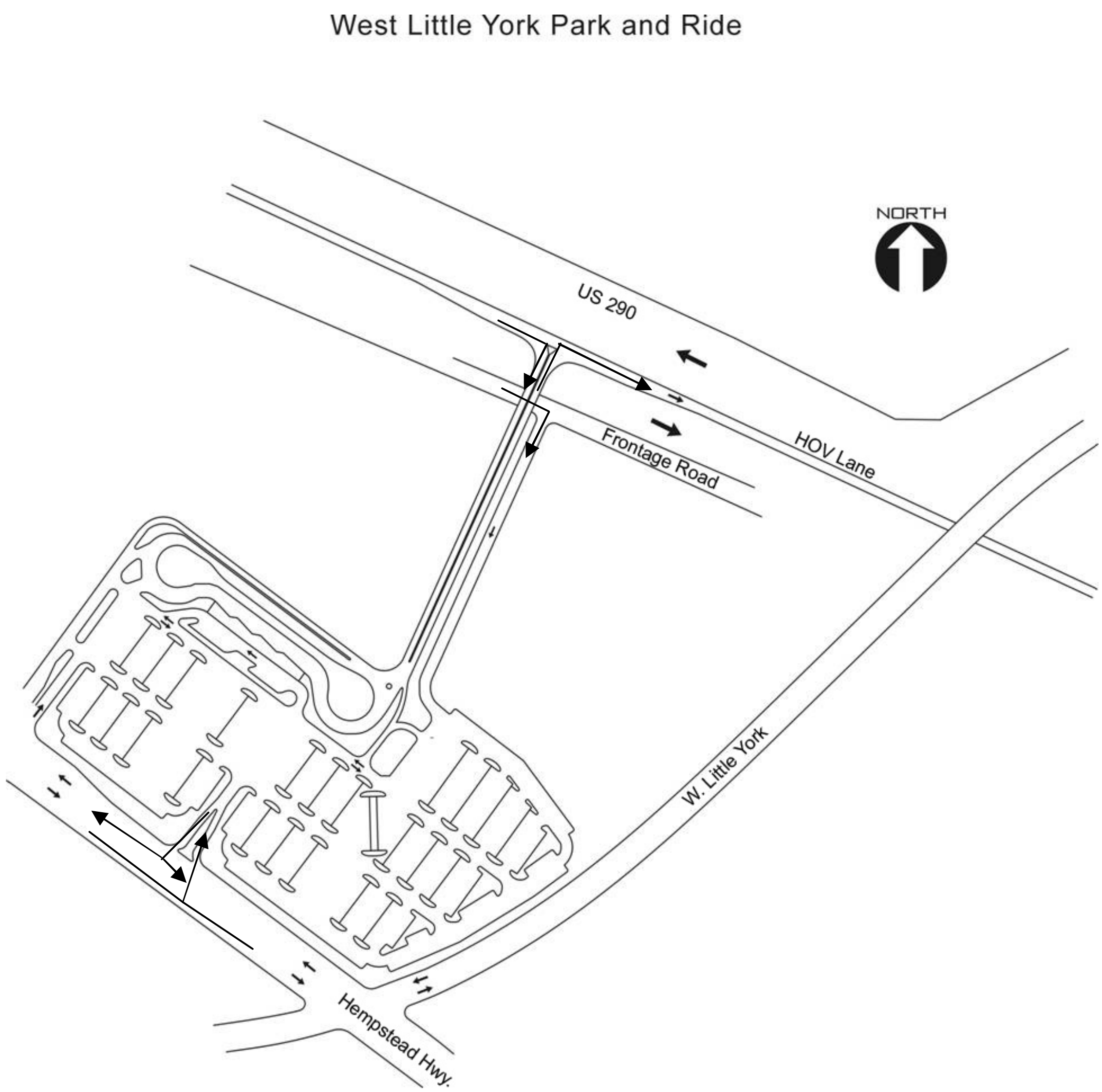

FIGURE 3.3 Schematic Map of the West Little York Park-and-Ride (*24*)

Closer to Downtown is the Pinemont Park-and-Ride. This facility is identified as Number 4 in the figure on page 28. The closest intersection to the point where the HOV access ramp enters the HOV lane is Bingle Road and the Northwest Freeway service road. Travel from this intersection to the HOV lane takes approximately 3 minutes, and requires passing through 3 traffic signals. This access point is shown in Figure 3.4.

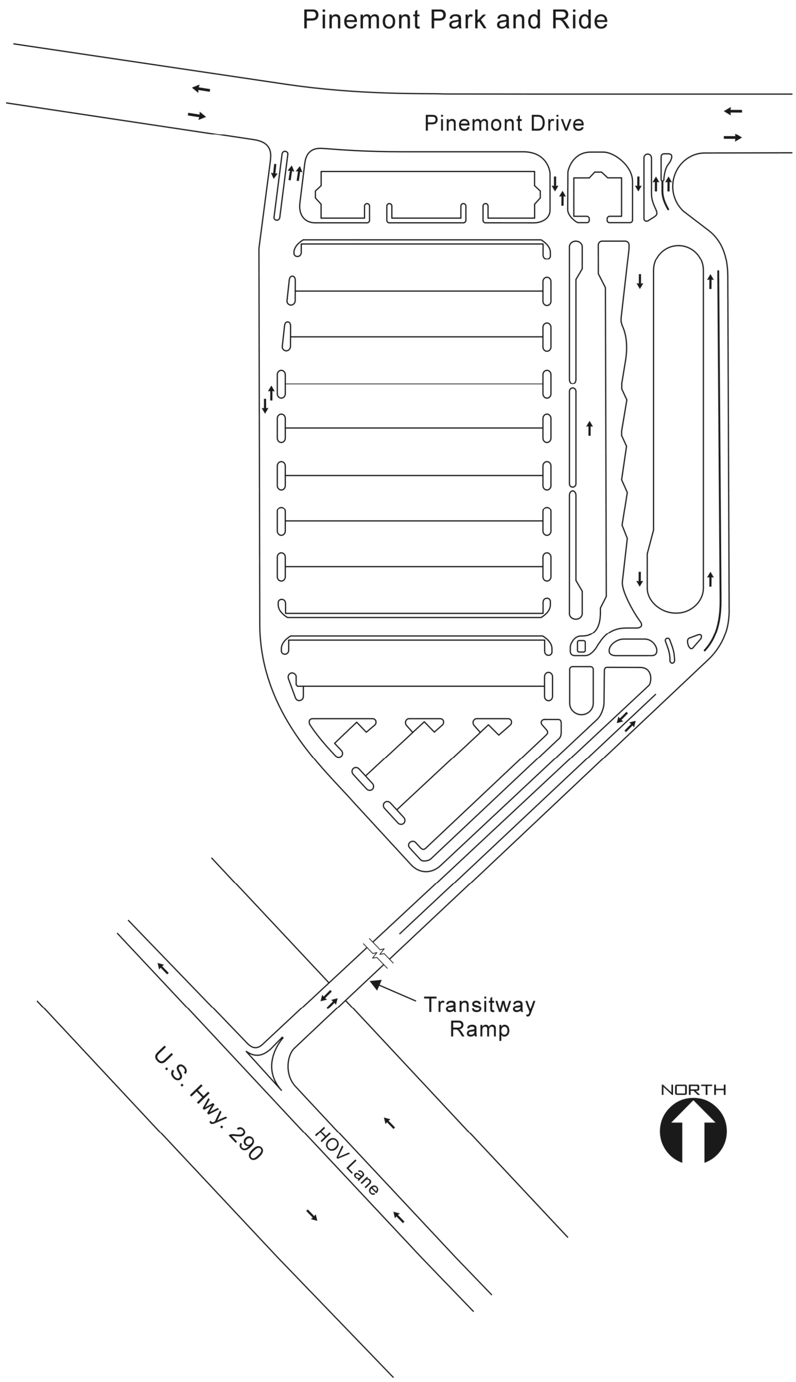

FIGURE 3.4 Schematic Map of Pinemont Park-and-Ride (*24*)

Another complex access point is the Northwest Transit Center, located at the intersection of the Katy Freeway and I-610. This access point is near the downtown end of the Katy Freeway HOV lane, and is the downtown end of the Northwest Freeway HOV lane. The schematic of this access point is shown in Figure 3.5, and is Number 2 in the figure on page 28.

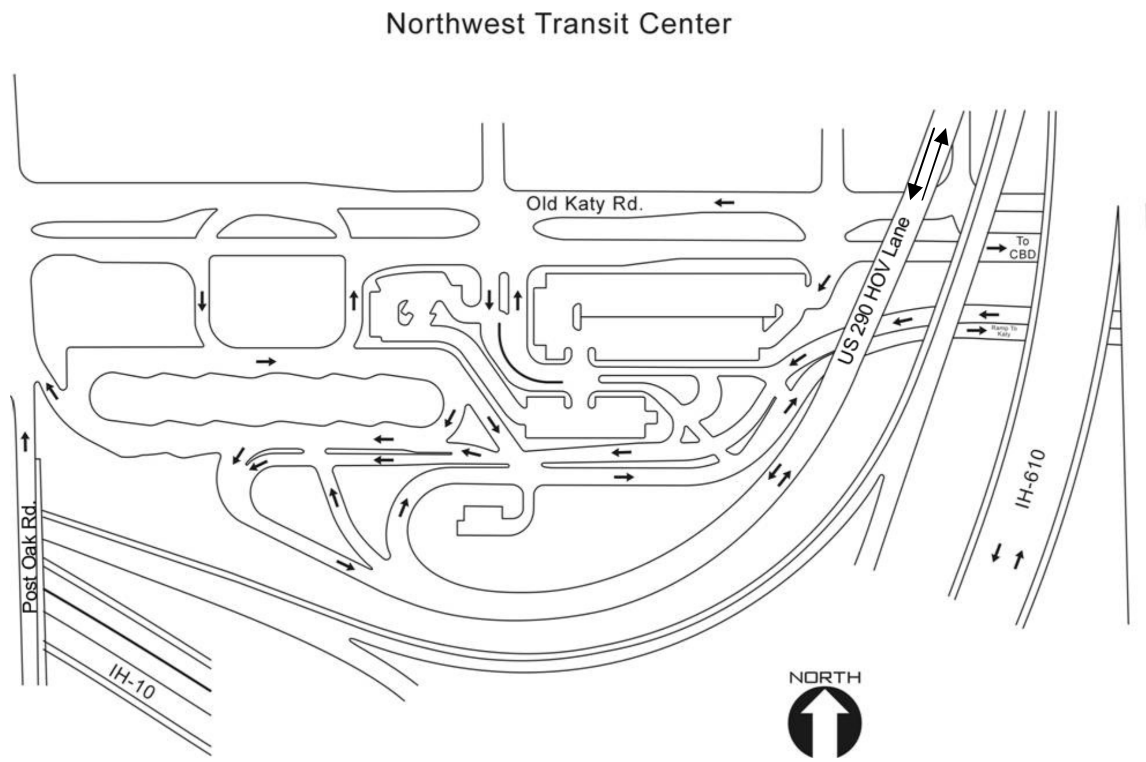

FIGURE 3.5 Schematic Map of the Northwest Transit Center (*24*)

The Northwest Transit Center has direct ramp access to the Northwest HOV lane, ramp access to the Katy HOV lane separated by one traffic signal, and is located at the intersection of two major streets. These streets, however, have no nearby access to the freeway main lanes. Travelers leaving this facility must drive two miles to the south on surface streets to access southbound I-610, or 1.75 miles east to enter the eastbound Katy Freeway from the Northwest Freeway. Navigating this transit center is a time consuming process, as well; it takes 1 minute and 40 seconds to travel from the intersection of Old Katy Road and Post Oak Road, which is shown in the upper left corner of the schematic, to the HOV lane. These travel time issues may decrease the appeal of carpooling and transit use for travelers who would be served by this facility. Part of the reason for this long navigation time is the complexity of the transit center, which is further demonstrated in Figures 3.6 and 3.7.

FIGURE 3.6 Old Katy Road Adjacent to the Northwest Transit Center

FIGURE 3.7 Aerial View of Northwest Transit Center

The three nearest median openings shown in Figure 3.6 are access to the Northwest Transit Center. The complexity of this area is evidenced by the amount of signage, indicating bus and HOV entries to the transit center, information for the nearby Post Oak ramp to the Katy Freeway HOV lanes, as well as Katy Freeway GPL access. This area is confusing to unfamiliar travelers, which may act as a deterrent to HOV and transit use for travelers.

The final example of complicated, time consuming access to Houston's HOV lanes is the Addicks Park-and-Ride. Although not numbered, this location is labeled in the figure on page 28. The nearest intersection to this facility is at Park Row Blvd. and State Highway 6. It takes approximately 2 minutes to travel from this intersection to the HOV lane, and requires passing through the signal at Park Row Blvd. and Highway 6. This access point is shown in Figure 3.8.

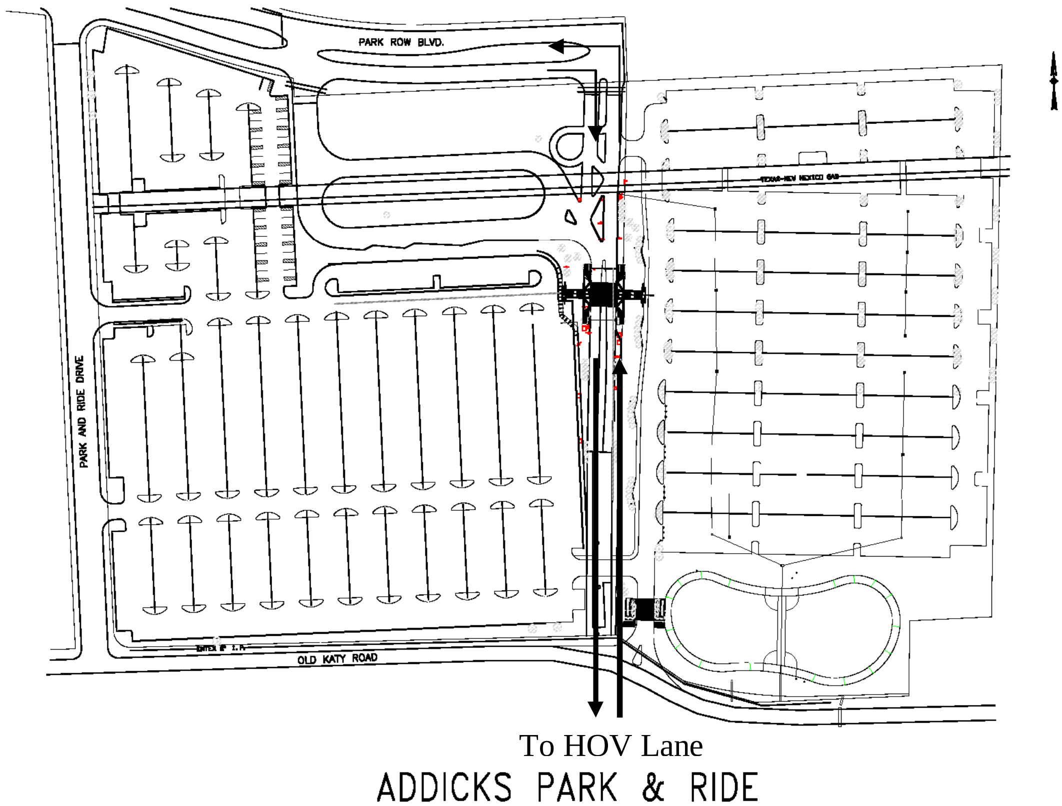

FIGURE 3.8 Schematic Map of Addicks Park-and-Ride (*24*)

3.1.3. HOV Lane Access Times

The times for HOV access were determined for HOV lane access points along the Northwest and Katy Freeways. This was accomplished by observing vehicles using the HOV access points, or by actually driving the access points. These observations were made on Tuesday, August 14, 2007 during the morning commute period. Weather was clear, warm, and humid. Northwest Freeway observations were made starting at 6:30 a.m. at the West Road slip ramp, and ending 8:15 a.m. at the Northwest Transit Center. Katy Freeway observations were made starting at 9 a.m. at the State Highway 6 slip ramp, and ended at 9:30 a.m. at the Eastern Extension slip ramp. The map of the HOV lanes and their access points can be seen in Figure 3.9. The observed access times for the access points are shown in Table 3.3 below. These access times were consistent in the peak and off-peak periods, as there is no congestion in the park-and-ride facilities.

FIGURE 3.9 Map of HOV Lanes Studied (*11*)

TABLE 3.3 HOV Lane Access Times

Roadway	Access Point	Access Type	Nearby Intersection	# Signals	Ramp to HOV Lane Travel Time
US 290	SH 6	Slip Ramp	US 290 and SH 6	1	n/a
US 290	NW Station	T-Ramp	US 290 and Eldridge	4	:33
US 290	W Little York P&R	T-Ramp	Freeway	0	:32
US 290	W Little York P&R	T-Ramp	Hempstead and Little York	1	:32
US 290	Pinemont P&R	T-Ramp	Bingle and US 290	3	:29
US 290	Dacoma	Double T-Ramp	Mangum and US 290	2	n/a
US 290	NW Transit Center	Ramp	Old Katy at Post Oak	1	:09
I-10 Katy	SH 6	Slip Ramp	n/a	0	n/a
I-10 Katy	Addicks P&R	T-Ramp	SH 6 and Park Row	1	:24
I-10 Katy	Gessner	Slip Ramp	n/a	0	n/a
I-10 Katy	Post Oak/NWTC	Ramp	Old Katy at Post Oak	1	:51

For some of the ramps, several observations of ramp travel time were made. At the Northwest Transit Station, ramp travel times of 32, 29, 43, and 29 seconds were observed, for an average of 33 seconds. At the West Little York Park-and-Ride, ramp travel times of 32, 35, and 29 seconds were observed, for an average of 32 seconds. Five observations were made at the Pinemont Park-and-Ride. Ramp travel times of 29, 21, 17, 60, and 19 seconds were observed, averaging 29 seconds. At the Northwest Transit Center, three observations of 9 seconds were made. Finally, at Addicks Park-and-Ride, ramp travel times of 28, 19, and 26 seconds were observed, for an average of 24 seconds.

3.1.4. ArcGIS Network Creation

Next, the data was manipulated for use in ArcGIS, a Geographic Information System software package (*25*). ArcGIS version 9.2 was used for the data reduction and analysis in this study. This software allows geographically related data to be tied together. As such, it includes a database management system, along with several geographic data analysis tools. These tools include geocoding tools, which allow the locations of objects to be placed on a map based on an address, coordinates, or other geographic data.

Also included is a network analysis extension, which allows networks to be created based on map data and other characteristics. This extension includes tools for creating routes on a network between geocoded or manually input points, and to determine the service area of a feature, such as the locations which lie within a certain network distance or travel time of a location. In this study, the service area tool was used to determine the travel time from respondents' origins to the nearest HOV and GPL entrance points, and the travel time to their destinations from the nearest exit points. Furthermore, ArcGIS facilitates the creation of presentation-grade maps by including tools which automatically generate accurate legends, scales, and appropriate feature names. This is by no means the limit of the tools included in ArcGIS 9.2, but is the list of the most important tools used in this analysis.

The basis of the analysis was the road network maps. These maps were in the form of TIGER line files from the United States Census Bureau, which are comprehensive maps of roadways for a given area, and include information such as length, name, and block number for each road. TIGER files can be obtained from the Census Bureau's TIGER webpage, at http://www.census.gov/geo/www/tiger/. County level TIGER maps were used, and the counties used included Harris, Montgomery, Chambers, Liberty, Galveston, Brazoria, Fort Bend, and Waller counties. These counties represent the Houston metropolitan area and its immediate surroundings.

While they are culled from the same location and are made by the same organization, the TIGER files do not line up perfectly at the boundaries of files. In this case, roads were not continuous across county lines. This was problematic, as many people live in one county in the Houston area, but work in another. To account for this shortcoming, principal routes such as major arterials and freeways were manually connected by adding short links between the discontinuous sections of the roadways using ArcGIS' file editing tools. This new file represented the Houston area map. Minor routes were not linked due to their high number, and the low likelihood that travelers would favor them over major routes, especially after travel time and functional class attributes were added to the roadway network.

Roadway functional classification was added to the roadway attributes for the combined Houston area map. This would later allow ArcGIS' network analyst to assign travelers' routes with preference for freeways and major arterials, a behavior observed in many travelers. Simple function classifications were used, and included HOV facilities, freeways, major arterials, and other roads. Functional classification was added as an attribute in the map attribute table. Roadways could be selected graphically on the map, or could be chosen by name in the attribute table, then assigned the appropriate classification.

For example, all roads were initially assigned a numerical functional classification of 6, which represented "other roads", and would be recognized as low choice routes when the network analyst was later developed. Then, for example, all roads named "I-10", "East Freeway", or "Katy Freeway" were given a functional classification number of 2, representing "Freeways". The map was then examined, and missing links were added and superfluous ones removed, such as service roads sharing the freeway's name.

To facilitate travel time based network routing in later steps, peak, shoulder, and off-peak travel times for each link were added to the attribute table. Freeways and HOV lanes were assigned travel times based on the speeds for each travel period as observed by Houston's Transtar Traffic Management System. These speeds were observed by the Automatic Vehicle Identification system used by Transtar in 2006, and were then reduced to weekday averages for the peak, shoulder, and off-peak periods. Peak periods were from 7 to 8 a.m. and 5 to 6 p.m., shoulder periods ran from 6 to 7 a.m., 8 to 11 a.m., 2 to 5 p.m., and 6 to 7 p.m., and off-peak periods were all other times. Travel times were thus the length of the segment divided by the segment operating speed. HOV ramp travel times were directly observed, and thus entered directly (see Table 3.3).

Speeds for arterials were assumed to be 35 mph in the shoulder and off-peak periods, and were assumed to drop to 30 mph in the peak periods. Speeds on other roads were assumed to be 20 mph all day.

Surprisingly, HOV lanes and their ramps were not included in the TIGER dataset, even though elements such as freeway onramps were. Thus, it was necessary to manually enter the HOV lanes into the maps, and to enter their attributes into the map attribute table. Each ramp was drawn as a discrete element, and the HOV lanes between each ramp were drawn as discrete polylines. This allowed the travel time, length, and name attributes to be entered for each ramp and HOV lane segment, and also allowed the individual ramps to be edited to ensure connections between the rest of the network and the HOV lanes.

From this map, which now included HOV lanes, travel time information, and functional classification information, a network was constructed using ArcGIS' network analyst extension. This network included impedance values for peak, shoulder, and off-peak travel times, travel distance, and functional classification for the roads in the Houston area, as well as what roads each road connects to. This network was later used by the researcher to check for appropriate roadway connectivity, to determine the routes survey respondents used, and to determine the travel time to HOV lane access points and GPL access points.

To ensure that these new elements properly connected adjacent roadways to the HOV lane, test origins and destinations were manually placed on elements near the HOV lane ramps. All test origins were placed in one shapefile, which is an ArcGIS file which contains both geographic location and attribute table information for all included elements. Likewise, all destinations were placed in their own shapefile. These origin-destination pairs were numbered, the first pair was named "1" for example, to instruct the network analyst to route from the point in the origin shapefile to the matching point in the destination shapefile. The network analyst was then used to create routes on the network from each origin to the appropriate destination. In cases where the route did not move along the expected path from the origin to destination, the ramp and adjacent elements were edited to ensure connectivity. The test was then repeated until all ramps were properly connected.

3.2. Data Combination and Reduction

3.2.1. Survey Data

The surveys were combined, relevant data was extracted, and errors were removed. This effort included the following steps:

- Identifying similar data categories between the surveys
- Converting the data in similar categories to a consistent format
- Consolidating the surveys into one database
- Removing respondents who did not indicate use of US-290 or I-10 Katy, the corridors of interest
- Quality control – checking the data for erroneous or missing values

In the first step, identifying similar categories between the surveys, involved determining which categories in one of the surveys was identical in both subject and reporting method as in the other survey. For example, the origin and destination cross-street categories could be directly combined because they report the same information in the same way. However, some categories such as vehicle occupancy could not be directly combined, although their content was the same, because one survey used binary variables to indicate which occupancies were and were not reported by the respondent, while the other survey used a numeric code to indicate occupancy or mode. In cases such as this, both sets of survey data were combined into one format. At this point, there were a total of 8139 respondents.

Then, respondents who did not indicate use of the Katy or Northwest Freeways were removed from the dataset. As these two corridors were the only ones in Texas with HOT lanes at the time of the surveys, and most respondents reported use of the Katy and Northwest Freeways, responses from non-HOT corridors were removed for consistency. In this step, the number of respondents was reduced to 4506, 55.4 percent of the original dataset.

Next, in order to control the quality of the dataset, respondents who did not indicate at least one origin and destination cross-street were removed from the dataset. Users who indicated at least one origin and destination cross-street were included, as with even one street, many users could be located within close proximity to their true origins and destinations. This was especially true when a single neighborhood street was listed as an origin. This step reduced the number of respondents to 4321, 53.1 percent of the original dataset, and 95.9 percent of the total respondents indicating use of the Katy and Northwest Freeways. This dataset of 4321 respondents was the basis for all later steps.

3.2.2. ArcGIS Data

After combining the surveys into one database, the dataset was reduced further based on the ability to geocode the respondents' reported origins and destinations, and the ability to connect the reported origins to the corresponding destinations. Geocoding is the process of locating the trip origins and destinations listed by the survey respondents on the map. This process was accomplished by first creating an address locator from the network dataset. This address locator can be set to match many address formats with the appropriate street, and accounts for spelling errors, and missing and erroneous data. In this case, address locators were made for each county's road network, and the address type was chosen as "US Streets", the typical address system used by the United States Postal Service, with a custom selection allowing the address to be comprised of the intersection of two streets.

Once address locators were created, the survey respondents origin and destination locations were then geocoded. Survey respondents' origins and destinations were geocoded in three batches each, one for peak period travelers, one for shoulder, and another for off-peak. This would later allow those users to be routed on the network with the proper travel time impedance characteristics, in turn facilitating proper route selection, and for travel time and time to HOV lane and GPL access points to be properly determined.

Geocoding was handled automatically, with the resulting locations shown on the map. Not all respondents' origins and destinations could be geocoded. The geocoding process allows for interactive placement of unmatched locations. Interactive matching allows the operator to manually alter the location characteristics, such as street name, of the data points being located. This process was useful, as in many cases parts of street names were interpreted as the street name suffix. For example, responses listing an origin or destination street of "Briar Forest" would be interpreted by the software as a street name of "Briar" with a suffix of "Forest" rather than the appropriate "Drive". Likewise, some users misspelled street names in such a way that the software could not properly interpret it, or would list a road by a name other than what it was called in the network dataset, such as calling the road "US 290" as opposed to "Northwest Freeway". Interactive matching was not undertaken for all unmatched respondents due to their large number. Instead, interactive matching for a smaller number of unmatched survey respondents was used to find which road names commonly listed by survey respondents could not be matched by the geocoding tool. Then, the names of roads in the survey database were changed to reflect what they were called in the network dataset. This improved the ability for the geocoding tool to locate survey respondents without a large time commitment to interactive geocoding.

Many respondents failed to list one or both of the streets comprising the intersection nearest to their origin or destination. In other cases, respondents misspelled the name of one of the streets, or listed the wrong type of road, such as indicating a Farm-to-Market road as a state highway, or using the generic "highway" label to denote an Interstate, U.S., state, or local highway. This resulted in the inability to geocode many of the respondents' origins or destinations. Of the 4321 total respondents who listed their primary commute route as either US-290 or I-10 Katy, it was possible to geocode 3347 respondent origins, or 77.0 percent, and 3458 destinations, or 79.5 percent.

Some geocoded respondent origins had no corresponding destination, and vise versa. Even in some cases where both an origin and destination was geocoded for a particular respondent, a route could not be found to connect the two. These additional issues limited the total number of routed respondents to 2624, representing 60.3 percent of the respondents who indicated that one of the routes of interest was their primary route. Then, travelers whose route was in the opposite direction of the morning HOV lane operation were removed from the dataset. 61.3 percent of the respondents traveled in the direction of HOV lane operations, leaving 1609 respondents whose origin and destination could be geocoded, a route found from the origin to the destination, and who traveled in the direction of interest. This represented 37.0 percent of the survey respondents who indicated they traveled on the freeways of interest. These 1609 respondents are examined in the subsequent sections.

4. DATA ANALYSIS AND RESULTS

This section summarizes the tasks that were necessary to investigate the influence of HOV and HOT lane access on lane utilization.

4.1. Data Analysis

The data analysis methods are described, along with difficulties encountered with the data analysis. Factors such as proximity to HOV or HOT lane access, the added travel time necessary to use the HOV lane access points, and the ramps and type of ramps, were examined to determine which factors, if any, may have influenced travelers' use of HOV or HOT lanes.

Travelers' least time path from origin to destination was determined with GIS software. The origin and destination cross-streets reported by the respondents were geocoded within the Houston-area roadway network. Then, network optimization tools were used to determine the optimum time path between origin-destination pairs. Survey respondents who traveled in the opposite direction of the HOV lanes in the morning were removed from the analysis, as the HOV lane, being unavailable to them, had no impact on their mode choice. This left 1609 respondents with geocoded origins and destinations. HOV lane access points were part of the GIS model, allowing the travel time a commuter would have to deviate from their least-time path to be determined. From this, HOV lane ingress and egress time was calculated and summed to determine the total HOV lane access time.

Based on vehicle occupancy and volume counts conducted on I-10 Katy and US-290 in 2003, the proportion of person-trips made by GPL and HOV lane in the corridors was calculated. The proportion of person movements by each mode in the off-peak, shoulder, and peak periods in the HOV lane is shown in Table 4.1. The proportion of person-movements by the GPLs and HOV lanes for each period is shown in Table 4.2.

TABLE 4.1 Proportion of Person-Movements in the HOV Lanes by Period

	HOV Lane Person-Movement Percentage						
Period	**BUS**	**VAN**	**SOV**	**HOV 2**	**HOV 3+**	**MC**	**Total**
Off-Peak	0	0	0	2418	0	0	2418
Shoulder	1774	316	235	7358	767	88	10538
Peak	11204	947	930	18388	4516	400	36385
Total	12978	1263	1165	28164	5283	488	49341
HOV Traveler Percentage	26.30	2.56	2.36	57.08	10.71	0.99	100
Overall Traveler Percentage	5.58	0.54	0.50	12.11	2.27	0.21	21.21

TABLE 4.2 Proportion of Person-Movements by GPL and HOV Lanes by Period

Period	**HOV Lanes Total**	**GPLs Total**	**Overall Total**	**HOV Lane Percentage**	**GPLs Percentage**
Off-Peak	2418	83990	86408	2.80	97.20
Shoulder	10538	49441	59979	17.57	82.43
Peak	36385	49872	86257	42.18	57.82
Total	49341	183303	232644	21.21	78.79

Overall, 78.3 percent of person-trips were made in the GPLs, whereas 21.7 percent were made in the HOV lane. Unfortunately, this ratio of person-trips did not correspond with the ratio of survey respondents using each type of lane. Of the routed survey respondents, only 58.6 percent used the GPLs, whereas 41.4 percent used the HOV lane. This discrepancy is most likely explained by the much higher response rate among surveys administered on transit buses or to travelers waiting for transit buses, among other factors. Other factors include the fact that travelers who use the HOT lanes, which are located on the HOV lanes, could be directly targeted in the surveys because their addresses were part of the HOT lane registration information. However, this presents a challenge, as the response ratio is incongruent with the observed conditions, and thus does not faithfully represent the characteristics of travelers in the corridor. These transit users, which represent 14.8 percent of the routed survey respondents, were retained in the dataset due to the fact that HOV lane access time does affect the duration of transit trips. While other factors may have greater influence over transit mode choice, the same can be said for HOV mode choice. As access characteristics are the variable in question for this study, and can be measured for transit as well as other mode choices, transit users were retained in this study.

The inconsistency between the survey data respondents' mode share and the mode share observed in the field was accounted for using poststratification. Poststratification corrects for differences between known proportions of strata and the proportions reflected in a sample using weighting. Poststratification is considered applicable and accurate when the population proportions are known, when there are more than 20 members of the sample in each stratum, and the effects of errors in the weights can be ignored (*26*). In this analysis, the two strata are GPL and HOV lane users, and the average daily traffic and average vehicle occupancy are known for both I-10 Katy and US-290, giving the population characteristics. Considering 926 of the routed survey respondents indicated use of the GPLs, and 683 indicated HOV lane use, the strata are easily within the safe size range. Furthermore, inaccuracies in the weighting factors for strata are minor sources of inaccuracy when compared with the daily variation in traffic characteristics, and individual mode, route, origin, and destination choices. Thus, the poststratification weighting technique is valid for this analysis. Poststratification weighting factors were determined using Equation 4.1, where W is the weighting factor, $p_{observed}$ is the proportion of person-movements actually made in the HOV lanes or GPLs, and p_{survey} is the proportion of overall survey respondents indicated use of the HOV lanes or GPLs. The weighting factor for respondents indicating HOV lane use was 0.47, while the weighting factor for respondents indicating GPL use was 1.46.

$$W = \frac{p_{observed}}{p_{survey}} \tag{4.1}$$

4.2. Results

The 1609 respondent surveys were examined for trends in traveler behavior with relation to HOV lane access. Potential underlying socioeconomic factors were also explored.

The outcome of these analyses was used to determine the types of HOV lane access which might be associated with greater levels of HOV lane use. Additionally, relationships between HOV lane access time and HOV lane use were examined. All statistical analyses used a level of significance of 95 percent.

4.2.1 Spatial Proximity to HOV Lane Access

The first factor examined was the proximity of the survey respondents' origins and destinations to the HOV lane access points. The proximity of survey respondents to HOV lane access points was used to determine how HOV lane use rates varied with distance from respondents' origins and destinations to HOV lane access points. These rates were then used to construct isographs depicting the spatial distribution of HOV lane use rates with respect to distance to the access point. The ratio of respondents who indicated that they used the HOV lane to total respondents, called the HOV lane user rate, was determined for various distances from the HOV lane access points. This analysis used a straight-line distance, rather than a network distance. The isograph for HOV user rate in the spatial stratifications is shown in Figure 4.1.

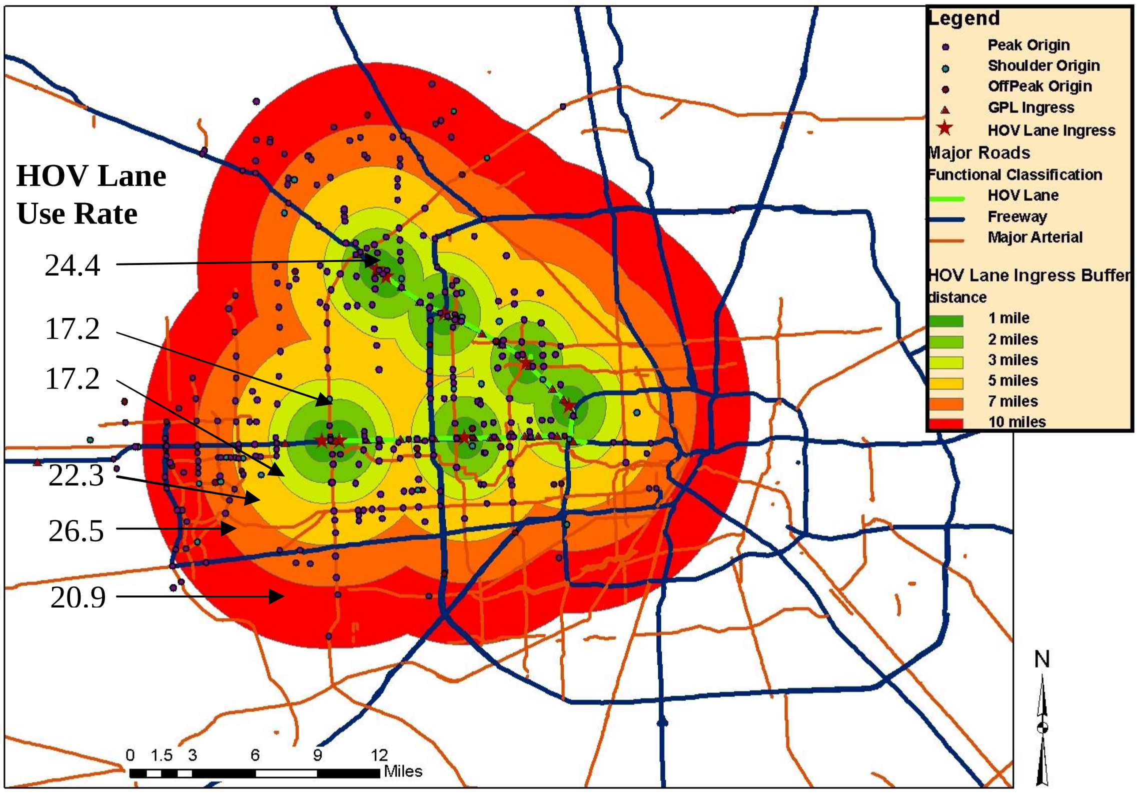

FIGURE 4.1 HOV Lane User Rate by Proximity to Ingress Points Isograph

There was no clear trend in HOV lane use rates with respect to distance to the HOV lane access points. This was not necessarily surprising, as distance neglects differences in travel time due to network characteristics, such as higher speed or congested roadways.

Tests for homogeneity of proportions were used to evaluate whether significant differences exist between HOV lane use percentages by proximity to access and egress points. This test is synonymous with the chi-square goodness-of-fit test (*27*). Equations 4.2 through 4.4 were used to determine the test statistic. The null hypothesis was that the proportions being compared are equal, while the alternative hypothesis was that they were not equal. The p-value, which is the probability of the null hypothesis being true given the value of the test statistic, was compared to the desired level of significance to determine the validity of the null hypothesis.

$$z_o = \frac{\hat{p}_1 - \hat{p}_2}{\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \tag{4.2}$$

Where $\hat{p} = \dfrac{x_1 + x_2}{n_1 + n_2}$ (4.3)

And $\hat{p}_i = \dfrac{x_i}{n_i}$ (4.4)

In these equations, x_i is the number of respondents in the stratum who indicated HOV lane use, while n_i is the total number of respondents in the stratum. Significance at the 95 percent level was desired. Thus, p-values less than .05 indicate that the null hypothesis is rejected, and that statistically significant differences exist. Otherwise, the null hypothesis is not rejected, and it cannot be concluded that significant differences exist.

The result of this test is shown in Table 4.3 below. Entries marked with an asterisk indicate significant differences, while entries without an asterisk cannot be shown to be significantly different from one another.

TABLE 4.3 Tests for Homogeneity of Proportions on HOV Use Rate by Distance to HOV Ingress

Distance to Ramp (miles)	HOV Lane Use Rate	p-value Distance to Ramp (miles)					
		0-1	1-2	2-3	3-5	5-7	7-10
0-1	24.5	--	0.07	0.07	0.56	0.60	0.44
1-2	17.2	0.07	--	1.00	0.13	0.01 *	0.37
2-3	17.2	0.07	1.00	--	0.13	0.01 *	0.38
3-5	22.3	0.56	0.13	0.13	--	0.18	0.73
5-7	26.5	0.60	0.01 *	0.01 *	0.18	--	0.19
7-10	20.9	0.44	0.37	0.38	0.73	0.19	--

The test for homogeneity of proportions indicated, for example, that the percent of respondents living from 1 to 2 and from 2 to 3 miles of the HOV lane ingress points that use the HOV lane (the HOV lane use rate) was significantly different from the 5-7 mile strata, but it was not significantly different from the other strata.

The same analyses were conducted on the distance from the HOV lane egress point to the respondents final destination. Figure 4.2 is the distance from egress isograph.

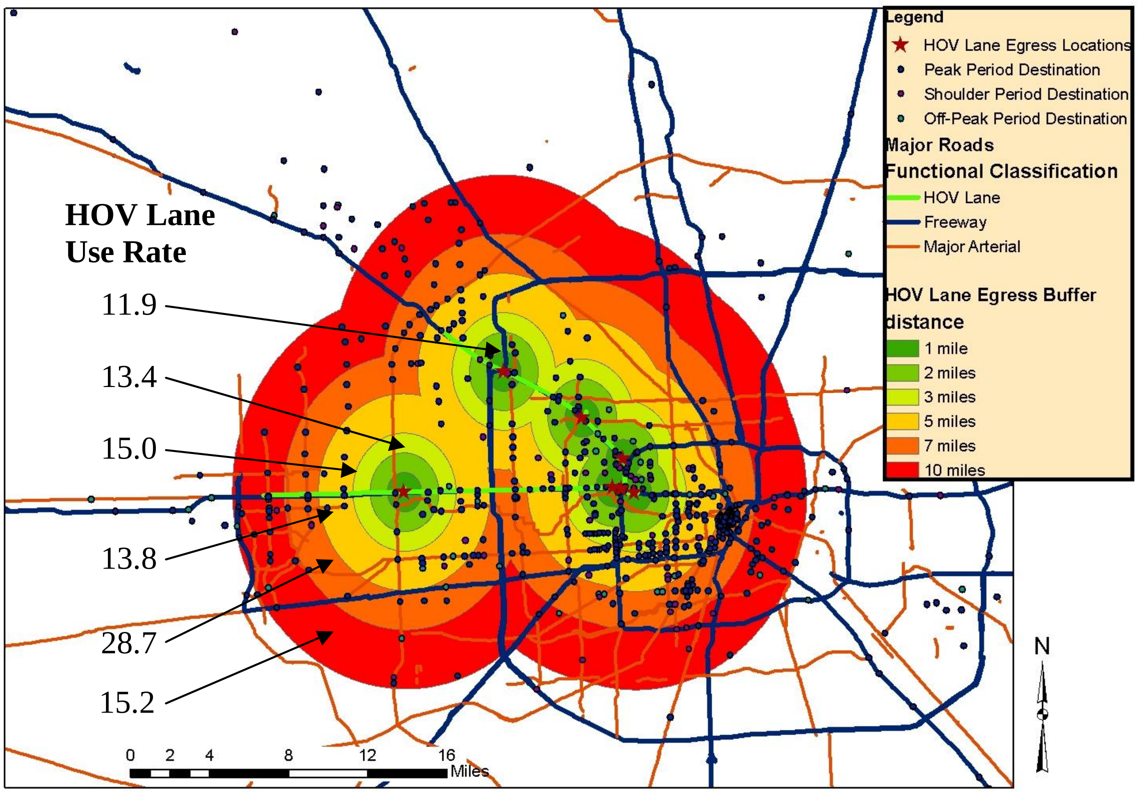

FIGURE 4.2 HOV Lane User Rate by Proximity to Egress Points Isograph

Notable in this isograph is the fact that the 5-7 mile stratum has almost twice the HOV lane user rate of any other strata. This stratum encompasses the downtown region, where job concentration is high. Jobs are the trip destination for most morning travelers, so it would be expected that a region with high job concentration would encourage greater carpooling. This large difference is also reflected in the tests for homogeneity of proportions on HOV lane user rate by proximity to egress points, the results of which are shown in Table 4.4. The percent of respondents traveling to destinations 5 to 7 miles from the nearest HOV lane access point was significantly different from all other strata. No significant differences could be demonstrated between the other strata.

TABLE 4.4 Tests for Homogeneity of Proportions on HOV Use Rate by Distance from HOV Egress

Distance to Ramp (miles)	HOV Lane Use Rate	p-value Distance to Ramp (miles)					
		0-1	**1-2**	**2-3**	**3-5**	**5-7**	**7-10**
0-1	11.8	--	0.74	0.45	0.63	0.00 *	0.50
1-2	13.4	0.74	--	0.70	0.93	0.00 *	0.73
2-3	15.0	0.45	0.70	--	0.71	0.00 *	0.97
3-5	13.8	0.63	0.93	0.71	--	0.00 *	0.75
5-7	28.7	0.00 *	0.00 *	0.00 *	0.00 *	--	0.00 *
7-10	15.2	0.50	0.73	0.97	0.75	0.00 *	--

Additionally, a test for homogeneity of proportions was conducted on the sum of the distance from the respondents' origins to the nearest ingress point and from their destination to the nearest egress point. The results of this analysis are shown in Table 4.5. Few statistically significant differences exist between the distance strata. The 3 to 5 miles stratum was significantly different from the 5-7, 7-10, 10-13, and 13-17 miles strata. The 2-3 miles stratum was significantly different from the 10-13 miles strata, and the 7-10 miles strata was significantly different from the 10-13 miles strata. Other strata were not found to be significantly different.

TABLE 4.5 Tests for Homogeneity of Proportions on HOV Use Rate by Combined Distance of Origin from HOV Lane Ingress and Destination from Egress

Distance to Ramp (miles)	HOV Lane Use Rate	p-value							
		Distance to Ramp (miles)							
		0-1	1-2	2-3	3-5	5-7	7-10	10-13	13-17
0-1	4.0	--	0.28	0.44	0.45	0.13	0.19	0.07	0.14
1-2	16.9	0.28	--	0.55	0.43	0.54	0.79	0.28	0.55
2-3	11.5	0.44	0.55	--	0.94	0.11	0.23	0.03 *	0.14
3-5	11.1	0.45	0.43	0.94	--	0.01 *	0.04 *	0.00 *	0.03 *
5-7	22.4	0.13	0.54	0.11	0.01 *	--	0.33	0.16	0.96
7-10	19.1	0.19	0.79	0.23	0.04 *	0.33	--	0.01 *	0.49
10-13	27.1	0.07	0.28	0.03 *	0.00 *	0.16	0.01 *	--	0.41
13-17	22.6	0.14	0.55	0.14	0.03 *	0.96	0.49	0.41	--

4.2.2. Added Access Time

The HOV lane user rate was also determined with respect to the added ingress and egress time necessary to use the HOV lane access points rather than the GPL access points. It was possible for users to have a negative added access time, indicating that accessing the HOV lane was less time consuming than accessing the GPLs. The percentage of survey respondents in each added access time strata is provided in Table 4.6.

TABLE 4.6 Percentage of Respondents by Added Travel Time

Added Travel Time (minutes)	Respondents	Percentage of Total Respondents
-3 to -2	30	1.9
0	300	19.2
1 to 2	88	5.6
3	246	15.8
4	203	13.0
5	168	10.8
6	86	5.5
7	141	9.0
8	94	6.0
9	83	5.3
10	54	3.5
12	36	2.3
14 to 18	32	2.0

GPL access points were included along the HOV lanes, as well as the nearest GPL access points beyond the HOV lanes. GPL access further from the ends of the HOV lane were not included. At both ends of the Katy Freeway HOV lane, and the outer end of the Northwest Freeway HOV lane, the access to the HOV lane is from slip ramps on the GPLs. Therefore, travelers with origins or destinations beyond the ends of the HOV lanes access the HOV lane from the freeway, not from surface streets. Comparing their HOV lane access to their nearest GPL access would not be a fair comparison. For example, someone living 40 miles west of downtown Houston may travel 2 miles to reach the GPLs, and 20 miles to the beginning of the Katy Freeway HOV lane. Not including these entry and exit points prevented respondents whose origins and destinations lied substantially beyond the HOV lanes, such as respondents living in Katy or working in downtown Houston, from being disproportionately affected in the access time calculations.

Figures 4.3 through 4.6 below show examples of the HOV and GPL ingress and egress time isographs during the peak period. Similar graphs were generated for the off-peak and shoulder periods, and all were used in the added access time calculations.

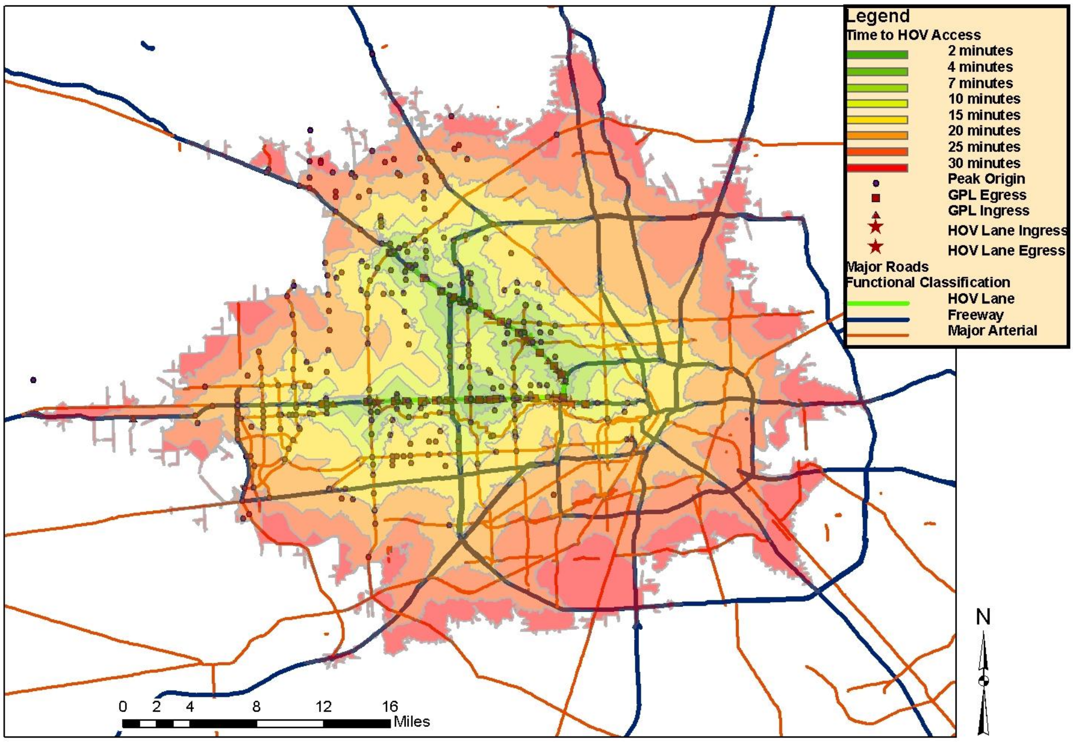

FIGURE 4.3 Peak Period HOV Lane Ingress Time

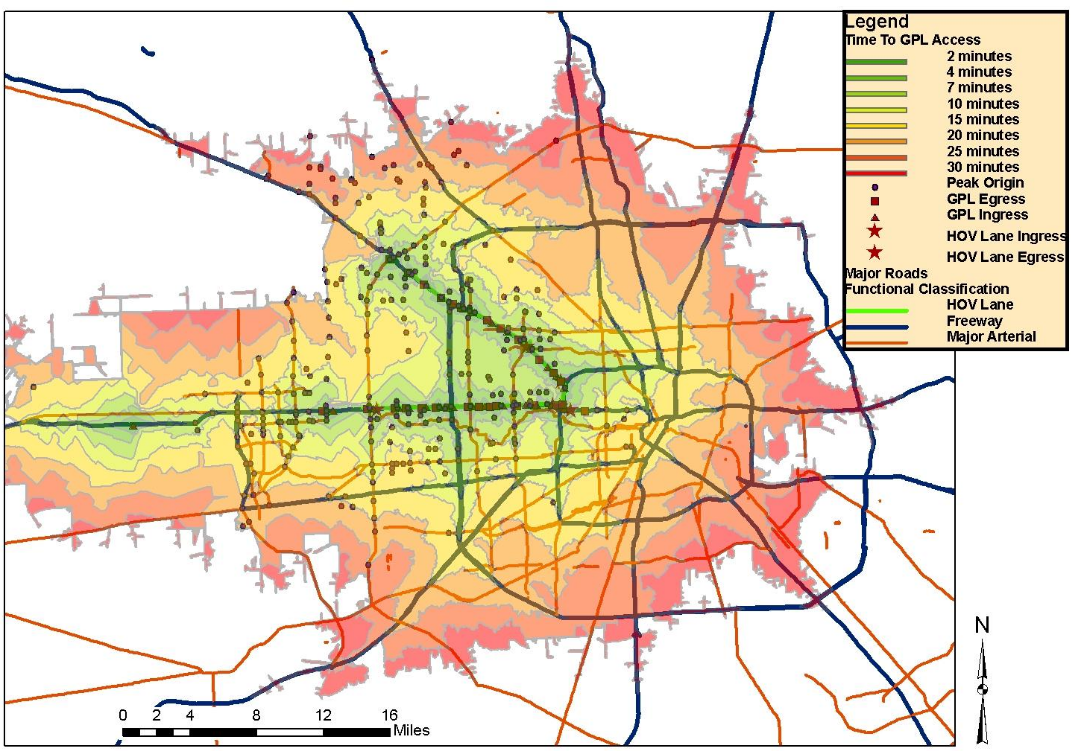

FIGURE 4.4 Peak Period GPL Ingress Time

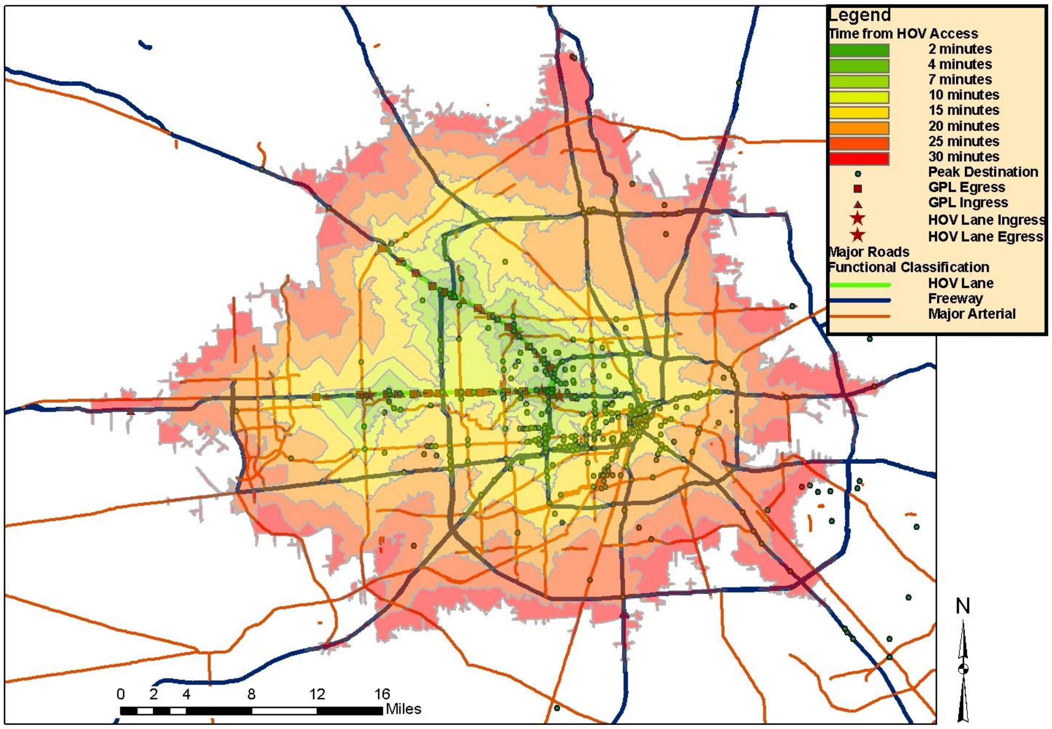

FIGURE 4.5 Peak Period HOV Lane Egress Time

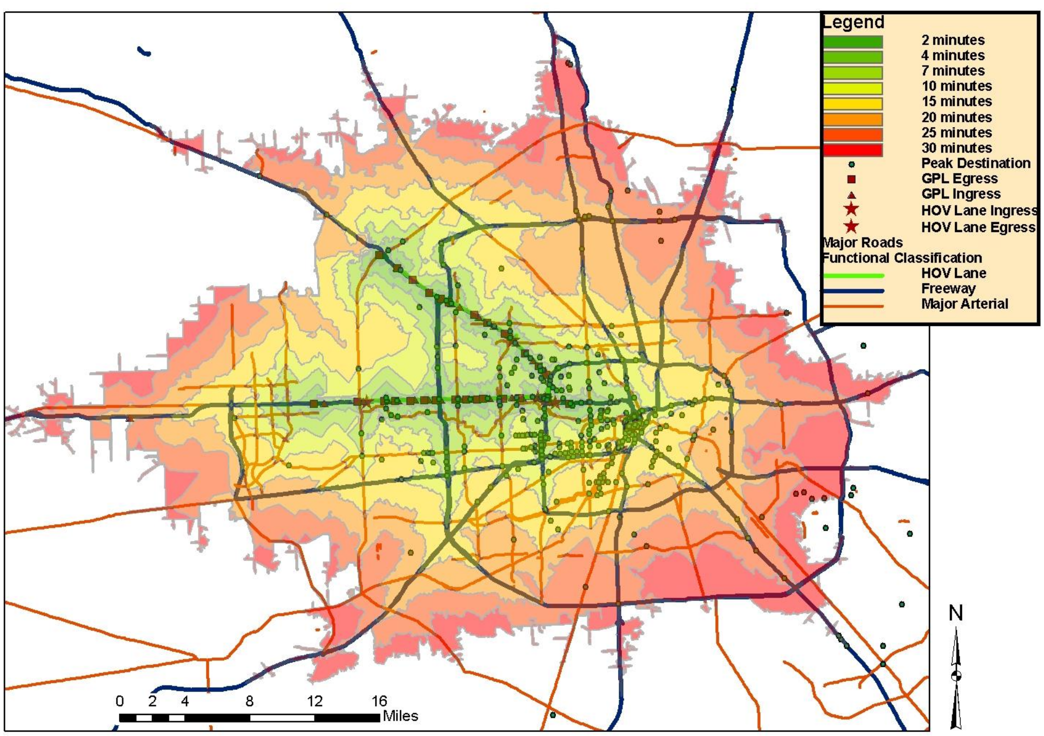

FIGURE 4.6 Peak Period GPL Egress Time

To determine the added access time, the least travel time necessary to reach the GPL and HOV lane entrances from the survey respondents' origins was determined. Likewise, the least travel time necessary to reach the respondents' destinations from the GPL and HOV lane exits was determined. The GPL access times were subtracted from the HOV lane access times to determine the added ingress and egress times. These times were then added together to determine the added access time. Table 4.6 includes these times aggregated into logical time blocks, which assured sufficient data in each group to draw meaningful conclusions.

Interestingly, HOV lane use rate seemed to generally increase as added travel time to access the HOV lane increased, the opposite of the expected result. The stratum with the most time saved by using HOV lane access points had the lowest HOV lane use rate, and the second highest added travel time strata had the highest HOV lane use rate. This is shown in Figure 4.7 below.

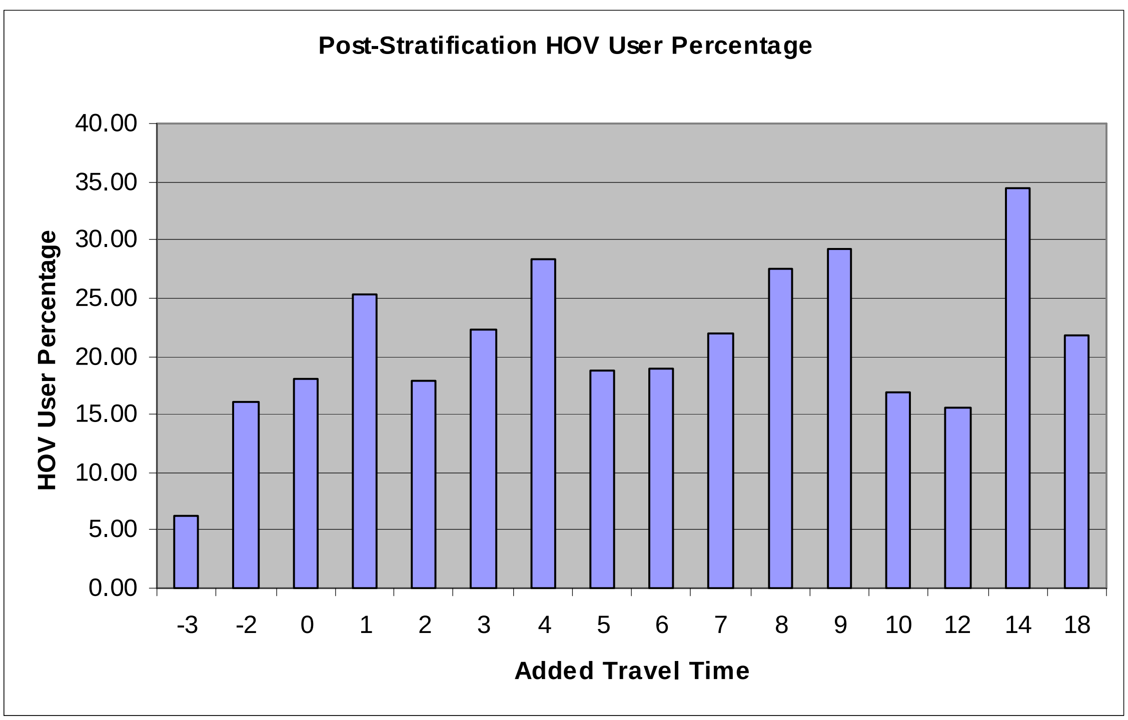

FIGURE 4.7 HOV Lane Use by Added Access Time

Tests for homogeneity of proportions were again used to determine if significant differences existed between the resulting added travel time strata. The results of this test are shown in Table 4.7. This test indicates that the 0 minutes added travel time stratum was significantly different from the 4, 8, and 9 minutes added travel time strata, and was not significantly different from the other strata. Additionally, the 4 and 5 minutes added travel time strata were significantly different from each other, but not any of the other strata. No other significant differences were found.

TABLE 4.7 Tests for Homogeneity of Proportions on HOV Use Rate by Added Travel Time to Access HOV Lane

Added Travel Time (min.)	HOV Lane Use Rate	p-value Added Travel Time (min.)												
		-3 to -2	0	1 to 2	3	4	5	6	7	8	9	10	12	14 to 18
-3 to -2	13.5	--	0.53	0.54	0.27	0.08	0.50	0.51	0.30	0.12	0.09	0.68	0.82	0.09
0	18.1	0.53	--	0.94	0.23	0.01 *	0.87	0.87	0.34	0.05 *	0.03 *	0.83	0.70	0.06
1 to 2	18.4	0.54	0.94	--	0.45	0.07	0.96	0.94	0.52	0.15	0.10	0.82	0.70	0.12
3	22.2	0.27	0.23	0.45	--	0.13	0.38	0.51	0.94	0.31	0.19	0.38	0.36	0.24
4	28.4	0.08	0.01 *	0.07	0.13	--	0.03 *	0.09	0.17	0.86	0.89	0.09	0.10	0.71
5	18.7	0.50	0.87	0.96	0.38	0.03 *	--	0.98	0.48	0.10	0.06	0.76	0.65	0.10
6	18.8	0.51	0.87	0.94	0.51	0.09	0.98	--	0.58	0.17	0.11	0.77	0.66	0.14
7	21.9	0.30	0.34	0.52	0.94	0.17	0.48	0.58	--	0.33	0.22	0.44	0.39	0.24
8	27.5	0.12	0.05 *	0.15	0.31	0.86	0.10	0.17	0.33	--	0.79	0.14	0.15	0.65
9	29.3	0.09	0.03 *	0.10	0.19	0.89	0.06	0.11	0.22	0.79	--	0.10	0.11	0.80
10	16.9	0.68	0.83	0.82	0.38	0.09	0.76	0.77	0.44	0.14	0.10	--	0.86	0.11
12	15.5	0.82	0.70	0.70	0.36	0.10	0.65	0.66	0.39	0.15	0.11	0.86	--	0.11
14 to 18	31.6	0.09	0.06	0.12	0.24	0.71	0.10	0.14	0.24	0.65	0.80	0.11	0.11	--

In conjunction with the previous test, a paired-samples t-test was conducted to determine if significant differences existed between the mean added access time for respondents who indicated that they traveled in the HOV lane versus the GPLs. This was intended to determine if HOV lane accessibility is a potential factor in the choice to use HOV lanes.

The mean HOV lane access time for HOV lane users was 4.74 minutes, more than half a minute greater than the mean GPL user access time of 4.22 minutes. The t-test resulted in a p-value of .004, resulting in the conclusion that a significant difference did exist between these groups. This result was very surprising, it was expected that respondents who chose to travel using the HOV lane would have lower average added access times than travelers in the GPLs. Yet the average traveler in the GPLs had a lower average travel time impediment to using the HOV lanes (if they had used the HOV lane) than the average traveler who used the HOV lanes.

4.2.3. Ratio of Added Access Time to Total Travel Time

The ratio of added access time to total travel time was also examined. This measure indicated which users spent a greater portion of their trip using the HOV lane access points. It was expected that users with smaller ratios would have been more likely to have used the HOV lanes. For these users, the time spent accessing the HOV lanes would have been more tolerable because, compared to the rest of their trip, it represented a smaller proportion of their total trip time.

This measure was an attempt to determine what proportion of travel time savings is necessary to offset the additional travel time HOV lane users incur in order access the HOV lane, along with other factors which affect HOV lane mode choice such as the inconvenience of carpooling and the additional travel time necessary to pick up and drop off carpool partners. Not modeling the GPL ingress and egress points substantially distant from the HOV lanes was especially important in this step. Including the distant GPL access points would have made the comparison unrealistic, as a traveler living outside the urban portions of the Houston area could spend half or more of their trip driving on the GPLs before reaching their nearest HOV lane access point.

The mean ratio of added access time to total travel time was .1755 for HOV users, lower than the .1873 mean for GPL users. A paired samples t-test was used to determine if these means were different in a statistically significant way. The resulting p-value of .62 indicated that no significant difference was found.

4.2.4. Ramps and Access Type

The HOV lane use rate was determined for respondents who were routed by the GIS software onto each of the HOV lane access points. Users could have entered or exited the HOV lane at these points. A total of 1224 respondents were routed onto the HOV lanes, meaning 385, or approximately 24 percent, of the routed respondents were not routed onto the HOV lane. These users were not routed to the HOV lane because a route including travel in the HOV lane was not their least travel time route. Several reasons for this exist, including that users may have had short trips, or trips with both origin and destination beyond the reach of the HOV lanes. This implies that those users would have to deviate more from the route with the shortest travel time to reach the HOV lane, making travel in the HOV lane a less attractive alternative. In other words, for those users, HOV access is so far out of their way that using the GPLs is actually faster, despite lower speeds. These explanations are consistent with the results of the previous analysis, which showed that respondents who indicated GPL use had a higher ratio of added access time to total travel time.

Additionally, Northwest Freeway HOV lane users bound for destinations near downtown Houston also used the Katy Freeway HOV lane between the Northwest Transit Center (NWTC) and the Eastern Extension slip ramp, meaning that they used four HOV lane ramps. Thus, the total number of ramp uses exceeds twice the number of routed survey respondents, because some respondents used more than two ramps. The respondents indicating HOV lane use routed onto each ramp, as well as the total number of respondents routed onto each ramp, are shown in Table 4.8. This table also indicates the Post-Stratification HOV user percentage, which indicates what proportion of survey respondents routed onto each ramp reported HOV lane use, adjusted for the difference in the proportion of respondents reporting HOV lane use as compared to the observed proportion of travelers using the HOV lanes in the corridors in question.

TABLE 4.8 Post-Stratification HOV Lane Use Rate by Ramp

Ramp	Ramp Type	HOV Users	Total Users	Post-Stratification HOV User %
SH 6	Slip	247	430	27.01
Addicks	T-Ramp	30	56	25.19
Gessner	Slip	30	175	8.06
Old Katy	Ramp	260	566	21.60
Eastern Extension	Slip	507	1021	23.35
West	Slip	178	414	20.21
NWTS	T-Ramp	43	78	25.92
Little York	T-Ramp	42	105	18.81
Pinemont	T-Ramp	12	55	10.26
Dacoma South	Ramp	14	51	12.91
Dacoma North	Ramp	6	19	14.85
NWTC	Ramp	263	562	22.00

Tests for homogeneity of proportions were again used to determine if significant differences existed between the use rates for each ramp. Rejection of this hypothesis implies that travel time from an HOV lane access point does affect HOV lane utilization. This test was also applied to the distance from a survey respondent's origin or destination to the nearest HOV lane access point to test for spatial proximity effects. If significant differences exist between HOV lane use with respect to added travel time or distance to the nearest access point, but not between the different access types, it implies that travel time, rather than convenience, is the most important factor in determining HOV lane use. The results of this test are shown in Table 4.9.

TABLE 4.9 Tests for Homogeneity of Proportions on HOV Use Rate by Ramp

		p-value											
		Ramp Location											
Ramp Location	HOV Lane Use Rate	SH 6	Addicks	Gessner	Old Katy	Eastern Extension	West	NWTS	Little York	Pinemont	Dacoma South	Dacoma North	NWTC
SH 6	27.0	--	0.77	0.00 *	0.05 *	0.14	0.02 *	0.84	0.08	0.01 *	0.03 *	0.24	0.07
Addicks	25.2	0.77	--	0.00 *	0.54	0.75	0.39	0.92	0.34	0.04 *	0.11	0.35	0.59
Gessner	8.1	0.00 *	0.00 *	--	0.00 *	0.00 *	0.00 *	0.00 *	0.01 *	0.61	0.29	0.32	0.00 *
Old Katy	21.6	0.05 *	0.54	0.00 *	--	0.43	0.60	0.39	0.52	0.05 *	0.14	0.48	0.87
Eastern Extension	23.3	0.14	0.75	0.00 *	0.43	--	0.20	0.61	0.29	0.02 *	0.08	0.38	0.54
West	20.2	0.02 *	0.39	0.00 *	0.60	0.20	--	0.26	0.75	0.08	0.21	0.57	0.50
NWTS	25.9	0.84	0.92	0.00 *	0.39	0.61	0.26	--	0.25	0.02 *	0.08	0.31	0.44
Little York	18.8	0.08	0.34	0.01 *	0.52	0.29	0.75	0.25	--	0.16	0.36	0.68	0.46
Pinemont	10.3	0.01 *	0.04 *	0.61	0.05 *	0.02 *	0.08	0.02 *	0.16	--	0.67	0.59	0.04 *
Dacoma South	12.9	0.03 *	0.11	0.29	0.14	0.08	0.21	0.08	0.36	0.67	--	0.83	0.13
Dacoma North	14.8	0.24	0.35	0.32	0.48	0.38	0.57	0.31	0.68	0.59	0.83	--	0.46
NWTC	22.0	0.07	0.59	0.00 *	0.87	0.54	0.50	0.44	0.46	0.04 *	0.13	0.46	--

The most striking conclusion that can be drawn from this table is that the Gessner slip ramp HOV use rate was significantly different from the other ramps, except for the Pinemont and the Dacoma North and South ramps. Additionally, the Pinemont T-ramp HOV use rate was significantly different from the State Highway 6, Addicks Park-and-Ride, Old Katy Road, Eastern Extension, Northwest Transit Station, and Northwest Transit Center use rates. Both of these notable differences reflect differences between HOV lane use rates at intermediate access points as opposed to access points near the ends of the HOV lanes. This may indicate that more HOV lane users travel the entire length of the HOV lane rather than using only part of the HOV lane. Furthermore, this may indicate that HOV lane travel is most convenient for travelers with long trips from origins in the suburbs beyond the reach of the HOV lanes to destinations near the urban core.

HOV lane use rate by ramp type was also explored to determine the effect of ramp design on HOV lane use. The post-stratification HOV lane use rates by ramp type are shown in Table 4.10 below.

TABLE 4.10 HOV Lane Use Rate by Ramp Type

Ramp	HOV Users	Total Users	Post-Stratification HOV User %
Slip	962	2040	22.17
Ramp	543	1198	21.31
T-Ramp	127	294	20.31

Tests for homogeneity of means were also used to determine if significant differences existed between HOV lane use rates for the different kinds of HOV lane access point, which include slip ramps, T-ramps, and other generic ramps. The results of this test are shown in Table 4.11. No significant difference between the HOV use rates for the ramp types were found. This indicates that ramp design is not a factor in the decision to use the HOV lanes or to form a carpool. Instead, this result combined with the differences in HOV lane use rate by ramp indicates that the convenience of the access point to travelers' origins and destinations is a much more important factor for encouraging carpooling and HOV lane use.

TABLE 4.11 Test for Homogeneity of Proportions on HOV Use Rate by Ramp Type

Ramp Type	HOV Lane Use Rate	Slip	Ramp	T-Ramp
Slip	22.2	--	0.57	0.47
Ramp	21.3	0.57	--	0.71
T-Ramp	20.3	0.47	0.71	--

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Logically, the proper placement and design of HOV lane access points would be expected to have an influence over the use of HOV lanes. However, while the proper location of HOV lane access does appear to have an impact on HOV lane use rates, the design of access has no discernable effect.

While significant differences were found, meaningful differences in HOV lane use rates could not be found between the distance from survey respondents' origin points and HOV lane ingress points. However, a statistically significant difference in the HOV lane use rate was found between respondents whose destination was 5 to 7 miles from an HOV lane egress point and the other distances to destinations. This 5 to 7 miles range, which includes Downtown Houston, had almost twice the HOV lane use rate of the other ranges. Downtown Houston has a high concentration of jobs, which has been shown by previous research to be a factor which encourages carpooling. This result supports the conclusion that placing HOV lane access close to activity centers supports carpooling, as concentrated origins or destinations make finding suitable carpool partners easier and more convenient.

The effect of the time necessary to access the HOV lane was surprising. This parameter ranged from 3 minutes saved to 18 minutes added. The categories of 0, 4, 8, and 9 minutes added were not significantly different from each other, but significantly different from almost every other category. Additionally, the 4 and 5 minutes added travel time strata were significantly different from each other, but not any of the other strata This was surprising, as it was expected that as the amount of added travel time to access the HOV lane increased, the HOV lane use rate would substantially decrease. In fact, the general trend was to see increasing HOV lane use rate as the time necessary to access the HOV lane increased. Furthermore, the average added access time for HOV users was 4.74 minutes, more than half a minute greater that the mean GPL user access time of 4.22 minutes, significantly different to the .004 level. This implies that HOV lane accessibility is not a factor in HOV lane mode choice, as logically those with lower HOV lane access times should be more likely to use the HOV lane, not less.

To control for differences in total travel time, the ratio of added access time to total trip time for HOV and GPL users was calculated. If HOV lane accessibility is a major factor in HOV lane mode choice, users with lower ratios should be more likely to use the HOV lane. However, the fact that there was not a significant difference between this ratio for HOV and GPL users indicates that HOV lane accessibility is not a major factor in HOV lane mode choice.

Finally, factors related to the HOV lane ramps themselves were explored. Ramps closer to the ends of the HOV lanes tended to have higher HOV lane use rates than intermediate ramps. There were some significant differences between the HOV lane use rates on the ramps, specifically between ramps at the ends of the HOV lanes and intermediate ramps. For example, the Gessner slip ramp HOV use rate was significantly lower than all other ramps except for the Pinemont, Dacoma North, and Dacoma South ramps, all of which are intermediate ramps. Similarly, the Pinemont T-ramp use rate was significantly different from the State Highway 6, Addicks Park-and-Ride, Old Katy Road, Eastern Extension, Northwest Transit Station, and Northwest Transit Center use rates. The Pinemont ramp is an intermediate ramp, while all the ramps which had significantly different use rates from it were near the ends of the HOV lanes.

Additionally, no statistically significant differences could be found between the HOV lane use rates for the different types of ramps. This indicates that the convenience of HOV lane access to a traveler’s origin and destination has an effect on HOV lane use rates, but that the convenience of the ramp itself has no effect.

Based on these results, it appears that the convenience of carpooling arrangements as well as the convenience of the HOV lane access points to traveler’s origins and destinations, rather than factors relating to the time necessary to access the HOV lanes or the convenience of HOV lane ramps themselves, has the largest effect on HOV lane use. This is important, as transportation practitioners tend to focus on travel time savings as the most important factor in the design of HOV lanes and their access.

While travel time savings is clearly an incentive to switch to higher occupancy modes, it appears that convenient carpool arrangements and conveniently placed HOV lane access are more important factors.

5.2. Recommendations

This analysis was performed using survey responses from travelers in two corridors in Houston, Texas which included HOV lanes. Mode choice and driver behavior may be different in other cities, or even on other corridors in the Houston area. A more comprehensive analysis of travelers in HOV corridors across the United States could yield conclusions more applicable to the nation as a whole.

The HOV corridors examined were both barrier-separated HOV lane facilities. This is the most prevalent type of HOV lane in Houston, but is one of the least common in the United States. An analysis which included buffer-separated facilities, which are more common, would be more useful for examining the HOV lane access factors which affect most HOV lane travelers.

Finally, the proportion of travelers who ride transit to access the HOV lanes on the Katy and Northwest freeways is relatively high. Analyzing traveler behavior in areas where the transit presence on the HOV lanes is not as strong, or separately analyzing express bus travelers and carpool travelers, would enhance the understanding of which HOV lane access factors affect the decisions of each class of HOV lane user. All of these avenues of future research would enhance the understanding of HOV lane traveler behavior, in turn allowing HOV lane access locations and design to be more closely tailored to the needs of travelers. This would increase the cost-effectiveness of HOV lane facilities, and increase the benefits of HOV lanes for the traveling public.

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APPENDIX

Houston HOT Lane Corridor Travel Survey

Part I: Please tell us about your most recent trip on the Katy Freeway (I-10) traveling towards downtown Houston during the work week (Monday through Friday).

1. What was the purpose of the trip?
   - ❑ Commuting (going to or from work)
   - ❑ Recreational / Social / Shopping / Entertainment / Personal errands
   - ❑ Work related (other than going to or from work)
   - ❑ School
   - ❑ Other (*specify*): ________________________________

2. What time of day did your trip start (for example, when did you leave your driveway)?

a.m. p.m. [ ] (*circle one*)

3. Would it have been possible to start your trip earlier or later?
   - ❑ I could have easily made the trip [ ] minutes earlier/later.
   - ❑ I could have made the trip anytime the same day.
   - ❑ I could not take the trip at any other time.

4. Do you allow for extra travel time due to possible traffic congestion on Katy Freeway (I-10)?

   □Yes □No

   If yes, how much extra time do you try to allow?__________ minutes.

5. Near what major cross streets did your trip start? *Example: Kingsland Blvd. and Mason Creek.*

   [ ] ***and*** [ ]

6. What time of day did your trip end (for example, when did you arrive at work)?

   [ ] ***a.m. p.m.*** (*circle one*)

7. Near what major cross streets did your trip end? *Example: Main St. and Texas Ave.*

	and	

8. Did you have to pay to park in Houston?

□Yes □No

If yes, how much does it cost per day? $__________

9. How many people, including yourself, were in the vehicle?

❑ 1 □ Took a bus → *If you travel by yourself or take the bus, please skip questions 10 to 12 and go to question 13.*

□ 2 □ 3 □ 4 □ 5 or more

❑ Motorcycle → *If you travel by motorcycle, please skip questions 10 to 11 and go to question 12.*

10. Who did you travel with? (*check all that apply*)

- ❑ Co-worker / person in the same or a nearby office building
- ❑ Neighbor
- ❑ Adult family member
- ❑ Another commuter in a casual carpool (also known as slugging)
- ❑ Child
- ❑ Other (*specify*): ______________________________________

11. How much extra time did it take to pick up and drop off the passenger(s)?

[ ] minutes

12. Did you use the High Occupancy Vehicle (HOV) lane? □ Yes □ No

If yes, how much travel time do you think you **saved** compared to the main lanes?

[ ] minutes.

13. How many ***total trips*** did you make during the past full work week (Monday to Friday) on the Katy Freeway? (Count each direction of travel as one trip, include trips on the HOV or main lanes)

[   ] trips

14. Do you sometimes use a route other than the Katy Freeway to make trips with a similar purpose?

□Yes □No

PART II: QUESTIONS REGARDING THE QUICKRIDE PROGRAM

During most of the time the HOV lane is open, vehicles with 2 or more occupants can use the HOV lane on the Katy Freeway (I-10), free of charge. However, during peak traffic periods (from 6:45 a.m. to 8:00 a.m. and 5:00 p.m. to 6:00 p.m.) toll-free use of the HOV lane is restricted to vehicles with 3 or more occupants.

Under a program called QuickRide, vehicles with only 2 occupants are permitted to travel on the HOV lane during peak traffic periods for a $2.00 toll per trip. Participants must set up a QuickRide account with their credit card before using the program. Enrollees are issued toll transponders that electronically charge the toll each time QuickRide is used. Additionally, a $2.50 monthly administration fee is charged to each account. For more information, please call 713-224-RIDE or 1-888-606-RIDE (toll free) or visit
http://www.hou-metro.harris.tx.us/services/quickride.asp

15. Prior to this survey, had you heard of the QuickRide program?
    - □ Yes → Go to Question 16
    - □ No → Go to Question 17

16. How did you hear about QuickRide? (*Check all that apply*)
    - ❑ TV
    - ❑ Radio
    - ❑ Mail
    - ❑ Newspaper
    - ❑ METRO website
    - ❑ Family / Friend
    - ❑ On the bus
    - ❑ I don't remember
    - ❑ Other (*specify*):______________________________

    → Go to Question 18

17. Now that you know about the QuickRide program would you be interested in using it?

□ Yes If Yes, what interests you **most** about QuickRide? (*check only one*)
- ❑ Being able to carpool with just one other person and still use the HOV lane
- ❑ Being able to use the HOV lane more often because it is much faster than the main freeway lanes
- ❑ Being able to use the HOV lane more often because the travel times on the HOV lane are consistent
- ❑ Being able to use the HOV lane more often because it is safer / less stressful than on driving main freeway lanes
- ❑ Other (*specify*): ______________________________

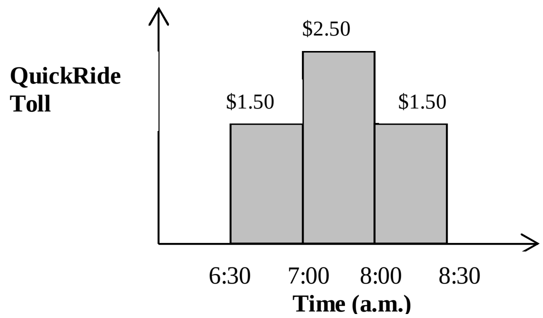
□ No If No – what are the primary reasons you would not use QuickRide? (*check all that apply*)
- ❑ Participation in a carpool is difficult / undesirable
- ❑ I do not want to set up a QuickRide account
- ❑ I do not have a credit card needed to set up an account
- ❑ I do not want to pay the $2.50 monthly administration fee
- ❑ I do not want a toll transponder in my car
- ❑ Access to the HOV lane is not convenient for my trips
- ❑ The HOV lane does not offer me enough time savings
- ❑ The HOV lane is sometimes just as congested as the main freeway lanes
- ❑ The QuickRide program is complicated or confusing
- ❑ I have the flexibility to travel at less congested times
- ❑ I do not want to pay the $2.00 per trip cost of QuickRide
- ❑ Other (*specify*): ______________________________

The questions in this part of the survey are to find out your views on a number of potential options for improving QuickRide. The options raised are only examples and do not represent local, state or federal policy.

18. Which of the following would cause you to try using QuickRide? (*Check all that apply*)
- ❑ Longer QuickRide operating hours
- ❑ The ability to pay to drive alone on the HOV lane
- ❑ A message sign that told me exactly how long the trip would take on the HOV lane before I paid to enter (for example, "At 7:15 a.m. travel to downtown on the HOV lane takes 14 minutes.")
- ❑ Increased traffic on main freeway lanes
- ❑ A reduction in the $2 QuickRide toll. Please enter the toll amount you would be willing to pay to try QuickRide: $ [ ]
- ❑ Other (*specify*) ______________________________

19. To maintain a smooth traffic flow, the QuickRide toll could change with the time of day. As shown in the graph below, lower tolls could be charged for travel at specific times (for example, 6:30 a.m. to 7:00 a.m.) and higher tolls during the most congested times (for example, 7:00 a.m. to 8:00 a.m.). What is your initial feeling regarding this option? (*Check only one*)

- ❑ Strongly favor
- ❑ Somewhat favor
- ❑ Indifferent
- ❑ Somewhat oppose
- ❑ Strongly oppose



20. The QuickRide toll could also change with the amount of traffic in the HOV lane. For example, if the HOV lane was not congested then the toll might be less than $2.00. However, if the HOV lane was very congested the toll might be higher than $2.00 to maintain the smooth flow of traffic. What is your initial feeling regarding this option? (*Check only one*)

- ❑ Strongly favor
- ❑ Somewhat favor
- ❑ Indifferent
- ❑ Somewhat oppose
- ❑ Strongly oppose

21. How do you feel about allowing people who drive alone to use the HOV lane for a higher toll than carpoolers?

- ❑ Strongly favor
- ❑ Somewhat favor
- ❑ Indifferent
- ❑ Somewhat oppose
- ❑ Strongly oppose

22. If you could drive alone on the HOV lane for the toll listed below, how often would you drive alone on the HOV lane?

Toll	*Number of trips per week (count each direction of travel as one trip)*
$3.00	____________
$4.00	____________
$5.00	____________
$6.00	____________

PART III: TRAVEL SCENARIOS

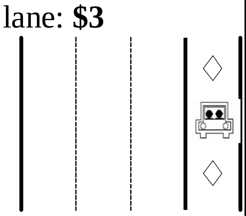
Each of the following questions asks you to choose between four potential travel choices on the Katy Freeway (I-10). For your most recent trip, please circle the one option that you would be most likely to choose if faced with these specific options. Remember that main lane traffic tends to be congested and could be slower than shown here if congestion is worse than usual. HOV lane traffic is fast moving. Peak hours are 6:45 a.m. to 8:00 a.m.

23. Circle the option you would choose:

A

Drive with one passenger on the HOV lane during peak hours.

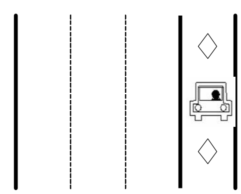
Travel time is **18** minutes (this includes 5 minutes to pick up and drop off the passenger)
Toll for HOV lane: **$3**



B

Drive alone on the HOV lane during peak hours.

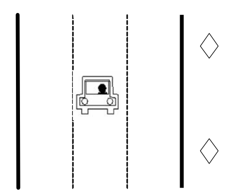
Travel time is **16** minutes
Toll for HOV lane: **$8**



C

Drive alone on the main freeway lanes during peak hours.

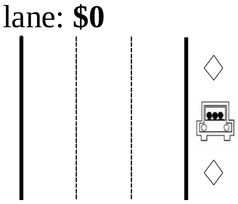
Travel time is **35** minutes
Toll: **$0**



D

Drive with two passengers on the HOV lane during peak hours.

Travel Time is **26** minutes (this includes 10 minutes to pick up and drop off the passengers)
Toll for HOV lane: **$0**

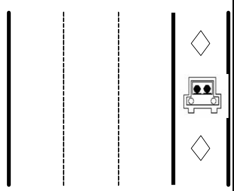


24. Circle the option you would choose:

A

Drive with one passenger on the HOV lane during peak hours.

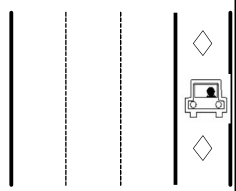
Travel time is **18** minutes (this includes 5 minutes to pick up and drop off the passenger)
Toll for HOV lane: **$2**



B

Drive alone on the HOV lane during peak hours.

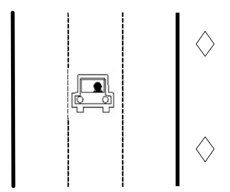
Travel time is **12** minutes
Toll for HOV lane: **$6**



C

Drive alone on the main freeway lanes during peak hours.

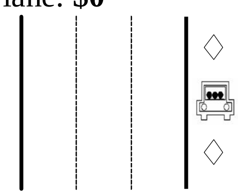
Travel time is **45** minutes
Toll: **$0**



D

Drive with two passengers on the HOV lane during peak hours.

Travel Time is **26** minutes (this includes 10 minutes to pick up and drop off the passengers)
Toll for HOV lane: **$0**

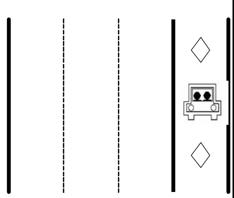


25. Circle the option you would choose:

A

Drive with one passenger on the HOV lane during peak hours.

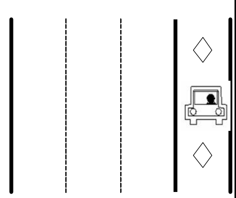
Travel time is **18** minutes (this includes 5 minutes to pick up and drop off the passenger)
Toll for HOV lane: **$2**



B

Drive alone on the HOV lane during peak hours.

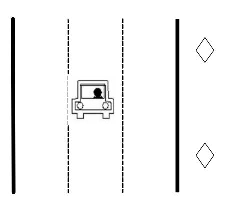
Travel time is **12** minutes
Toll for HOV lane: **$4**



C

Drive alone on the main freeway lanes during peak hours.

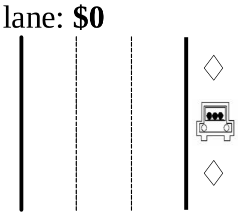
Travel time is **25** minutes
Toll: **$0**



D

Drive with two passengers on the HOV lane during peak hours.

Travel Time is **22** minutes (this includes 10 minutes to pick up and drop off the passengers)
Toll for HOV lane: **$0**

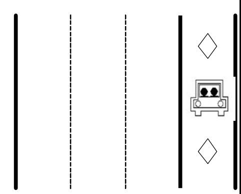


26. Circle the option you would choose:

A

Drive with one passenger on the HOV lane during peak hours.

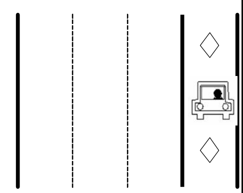
Travel time is **18** minutes (this includes 5 minutes to pick up and drop off the passenger)
Toll for HOV lane: **$1**



B

Drive alone on the HOV lane during peak hours.

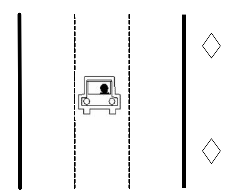
Travel time is **16** minutes
Toll for HOV lane: **$6**



C

Drive alone on the main freeway lanes during peak hours.

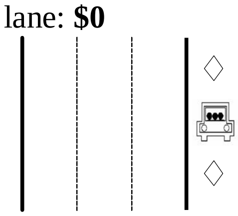
Travel time is **35** minutes
Toll: **$0**



D

Drive with two passengers on the HOV lane during peak hours.

Travel Time is **26** minutes (this includes 10 minutes to pick up and drop off the passengers)
Toll for HOV lane: **$0**



PART IV: USER INFORMATION

The following questions will be used for statistical purposes only and answers will remain confidential. All of your answers are very important to us and in no way will they be used to identify you.

27. What is your age?
- ❑ 16 to 24
- ❑ 25 to 34
- ❑ 35 to 44
- ❑ 45 to 54
- ❑ 55 to 64
- ❑ 65 and over

28. What is your gender?
- ❑ Male
- ❑ Female

29. Please describe your household type.
- ❑ Single adult
- ❑ Unrelated adults (e.g. room-mates)
- ❑ Married without child
- ❑ Married with child(ren)
- ❑ Single parent family
- ❑ Other (*specify*): ______________________________

30. Including yourself, how many people live in your household?

31. All together, how many motor vehicles (including cars, vans, trucks, and motorcycles) are available for use by members of your household?

32. What category best describes your occupation?
   - ❑ Professional / Managerial
   - ❑ Technical
   - ❑ Sales
   - ❑ Administrative / Clerical
   - ❑ Manufacturing
   - ❑ Stay-at-home homemaker / parent
   - ❑ Student
   - ❑ Self employed
   - ❑ Unemployed / Seeking work
   - ❑ Retired
   - ❑ Other *(specify)*: ________________________________

33. What is the last year of school you have completed?
   - ❑ Less than high school
   - ❑ High school graduate
   - ❑ Some college / Vocational
   - ❑ College graduate
   - ❑ Postgraduate degree

34. What was your annual household income before taxes in 2002?
   - ❑ Less than $10,000
   - ❑ $10,000 to $14,999
   - ❑ $15,000 to $24,999
   - ❑ $25,000 to $34,999
   - ❑ $35,000 to $49,999
   - ❑ $50,000 to $74,999
   - ❑ $75,000 to $99,999
   - ❑ $100,000 to $199,999
   - ❑ $200,000 or more

35. Please list any comments or suggestions you have regarding travel in the Katy Freeway (I-10) corridor:

____

____

____

Thank you for your participation.

Managed Lane Survey

Texas Department of Transportation

HOUSTON TRAVEL SURVEY

The Texas Department of Transportation (TxDOT) is studying new ways to improve traffic flow along major freeways in Texas. We need your help and input on these concepts for the Houston area. This 15 minute survey will help TxDOT better plan, implement, and operate freeway facilities into the future. While you are not obligated to answer the questions on the survey, the information you provide will be very valuable as we work to improve travel. Your answers on the survey will be anonymous and remain confidential -- only aggregate results will be reported.

This survey is being conducted by the Texas A&M University. If you have any questions regarding the survey, please contact the Principal Investigator, Dr. Mark Burris, at mburris@tamu.edu. This research study has been reviewed by the Institutional Review Board (IRB)- Human Subjects in Research. For problems or questions regarding subjects' rights, you may contact the IRB through Ms. Angelia M. Raines, Director of Research Compliance, (979) 458-4067.

1. From the list below, which road do you travel on most frequently? Choose only one.

O Beltway 8 (Sam Houston) O I-10 East (East Freeway) O I-10 West (Katy Freeway)
O I-45 South (Gulf Freeway) O I-45 North (North Freeway) O I-610 (The Loop)
O SH-225 (LaPorte Freeway) O SH-288 (South Freeway) O US-59 North (Eastex Freeway)
O US-59 South (Southwest) O US-290 (Northwest Freeway) O NONE OF THESE

2. What is the main purpose of most (or all) of these trips? Choose only one.

O Commute to work O Work related (not commuting) O School
O Recreational / Shopping / Errands O Other: ______________________

3. When do you generally travel on this road? Choose ALL THAT APPLY.

☐ Early morning (12 am – 6 am) ☐ Morning Peak (6am – 9 am) ☐ During the day (9am – 4pm)
☐ Evening Peak (4pm – 6:30 pm) ☐ Late evening (6:30 pm – 12 am)

4. How many miles is your typical trip on this highway? ________ miles

5. How many one-way trips do you make during a full week on this highway? ________ trips

6. How many people are there in your household? ________ people

7. How many vehicles (cars, trucks, motorcycles) are available for use in your household? ________ vehicles

8. In what ZIP codes do you begin your trip (such as your home) and end your trip (such as your place of work)?

________ ZIP code (BEGINNING of trip) ________ ZIP code (END of trip)

9. If you pay to park at your destination, how much do you typically pay each day? $ ________

10. If you pay a toll or bus fare on your trip, how much do you typically pay each day? $ ________

11. How do you typically travel on this highway? Choose only one and complete the appropriate questions.

O DRIVE BY MYSELF OR MOTORCYCLE

What do you think are the most important reasons why you do not carpool or vanpool? Check all that apply.

- ☐ I cannot find any one with the same location and schedule as mine
- ☐ People may have traits that I do not agree with (such as a smoker, excessive talker, etc.)
- ☐ I like the flexibility I have if I do not carpool or vanpool
- ☐ I need a vehicle during the day
- ☐ I have other stops to make, like shopping, or picking up kids
- ☐ I like to listen to the radio
- ☐ I appreciate the 'alone time'

O RIDE WITH 1 OR MORE PEOPLE (CARPOOL) OR VANPOOL

Number of TOTAL people in your carpool or vanpool? ____________ people

Who do you generally travel with? Check all that apply.

- ☐ Co-workers / persons in the same or a nearby office building
- ☐ Neighbors
- ☐ Adult family members
- ☐ Another commuter in a casual carpool
- ☐ Child

How important are the following factors in the formation of your current carpool/vanpool? Please rank your choices on a scale of 1 to 5.

1 = Not at all Important, 3 = Somewhat Important, 5 = Very Important

Sharing the cost of fuel	1	2	3	4	5	n/a
Access to HOV lanes	1	2	3	4	5	n/a
Access to preferred parking at work	1	2	3	4	5	n/a
Being able to relax as someone else is driving	1	2	3	4	5	n/a
Being able to get some work done while riding	1	2	3	4	5	n/a
Travel time savings due to carpooling/vanpooling	1	2	3	4	5	n/a
Existence of a carpool/vanpool partner matching program	1	2	3	4	5	n/a
Encouraged by a program at work	1	2	3	4	5	n/a
Enjoy traveling with others	1	2	3	4	5	n/a
Doing my part to help the environment / society	1	2	3	4	5	n/a
Carpooling with kids for school or day care center	1	2	3	4	5	n/a
Subsidized cost of a vanpool	1	2	3	4	5	n/a

Of your typical trips per week, how many trips do you carpool/vanpool? __________ trips

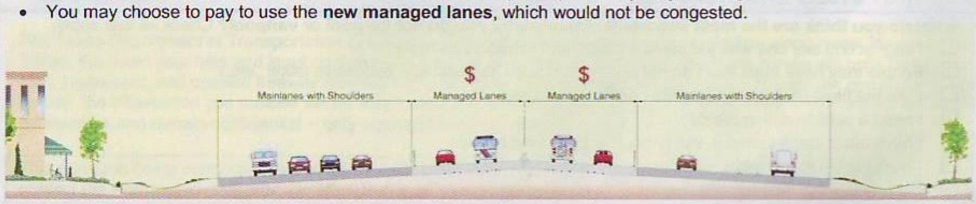
O RIDE ON A BUS OR TRAIN

What is your primary reason for traveling by bus or train? Choose only one.

- O It is cheaper than driving a car
- O It is convenient for me to catch the bus or train
- O I do not need to wait long if I miss the bus or train as they run frequently
- O The trip takes less time than by a car
- O I do not have a car available for these trips

Managed lanes are new lanes in the middle of existing freeways (similar to an HOV lane) that you can use if you pay a toll, collected electronically so that there would be no toll booths. With managed lanes, you have at least two choices:

- You may continue to use the **regular main lanes** for free (no toll), but they may be congested.
- You may choose to pay to use the **new managed lanes**, which would not be congested.



12. Would you be interested in using the Managed Lanes? Choose only one and complete the appropriate questions.

O YES – I would be interested in using the managed lanes

Please let us know what features you like most about the managed lane concept. Please rank your choices on a scale of 1 to 5, with 1 being a feature that is not important to you, up to 5 being a critical feature.

1 2 3 4 5
Not at all Important — Somewhat Important — Very Important

Being able to travel alone and still use the managed lanes	1	2	3	4	5	n/a
Being able to ride the bus on the managed lanes	1	2	3	4	5	n/a
Being able to travel faster than the main freeway lanes	1	2	3	4	5	n/a
More reliable travel times on the managed lanes than the regular lanes	1	2	3	4	5	n/a
Being able to use the managed lanes in a carpool or vanpool	1	2	3	4	5	n/a
The managed lanes will not have large trucks	1	2	3	4	5	n/a
The managed lanes will be less stressful than the regular lanes	1	2	3	4	5	n/a
Other factor: ______________________	1	2	3	4	5	n/a

O NO – I would NOT be interested in using the managed lanes

Please let us know what features of managed lanes are the most important in your decision not to use them. Please rank your choices on a scale of 1 to 5, with 1 being not at all important to you, up to 5 being a critical feature.

1 2 3 4 5
Not at all Important — Somewhat Important — Very Important

I do not have a credit card needed to set up an electronic toll account	1	2	3	4	5	n/a
I use the bus or train, and will not change to managed lanes	1	2	3	4	5	n/a
I do not want a toll transponder (toll tag) in my car	1	2	3	4	5	n/a
The managed lane concept is complicated or confusing	1	2	3	4	5	n/a
I have the flexibility to travel at less congested times on the toll-free lanes	1	2	3	4	5	n/a
I do not want to pay the toll cost of using managed lanes	1	2	3	4	5	n/a
Other factor: ______________________	1	2	3	4	5	n/a

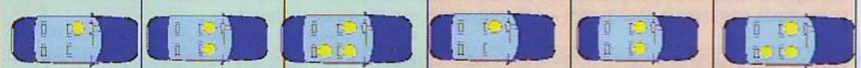
13. The toll on Managed Lane could change with the amount of traffic. For example, when traffic is heavy and more travelers want to use the managed lane, then the toll is higher. This ensures that the managed lanes do not become congested. What is your initial feeling regarding this option?

O Strongly favor O Somewhat favor O Indifferent O Somewhat oppose O Strongly oppose

14. How do you feel about charging carpoolers a smaller toll to use the managed lane than those who drive alone?

O Strongly favor O Somewhat favor O Indifferent O Somewhat oppose O Strongly oppose

15. The following four scenarios ask you to choose among a few potential travel choices. You are choosing between different toll prices, total passengers in your car, and travel times for each scenario. **For a typical trip, please check the one option <u>for EACH ROW</u> that you would be most likely to choose if faced with these specific options.** Remember that regular lane traffic (in orange) tends to be congested and could be slower than managed lane traffic (in light blue).

	Managed Lane Options			**Non-Toll (Regular) Lane Options**		
	Drive Alone	Drive with 1 passenger	Drive with 2 passengers	Drive Alone	Drive with 1 passenger	Drive with 2 passengers
						
Travel Time	**14 min**	**19 min**	**24 min**	**21 min**	**26 min**	**31 min**
Scenario 1 →	O $ 6.25	O $ 6.25	O $ 0.00	O FREE	O FREE	O FREE
Scenario 2 →	O $ 12.50	O $ 12.50	O $ 0.00	O FREE	O FREE	O FREE
Scenario 3 →	O $ 2.00	O $ 2.00	O $ 0.00	O FREE	O FREE	O FREE
Scenario 4 →	O $ 9.50	O $ 9.50	O $ 0.00	O FREE	O FREE	O FREE

The following questions will be used for statistical purposes only and answers will remain confidential. All of your answers are very important to us and in no way will they be used to identify you.

16. What is your age? Choose only one.
O 16 – 24 O 25 – 34 O 35 – 44 O 45 – 54 O 55 – 64 O 65 and over

17. What is your ethnicity? Choose only one.
O Caucasian O Afro-American O Hispanic O Asian O Native American O Other

18. Please describe your household type. Choose only one.
O Single adult O Unrelated adults O Married without child O Married with child(ren) O Single parent O Other

19. What category best describes your occupation? Choose only one.

O Professional / Managerial	O Technical	O Sales	O Student
O Restaurants / Retail	O Administrative / Clerical	O Manufacturing	O Construction
O Homemaker / Parent	O Self-Employed	O Unemployed	O Retired

20. What was your annual household income before taxes in 2005? Choose only one.

O Less than $10,000	O $10,000 to $14,999	O $15,000 to $24,999	O $25,000 to $34,999
O $35,000 to $49,999	O $50,000 to $74,999	O $75,000 to $99,999	O $100,000 to $149,999
O $150,000 to $199,999	O $200,000 or more		

21. What is the last year of school you have completed? Choose only one.
O Less than high school O High school O Some college / vocational O College O Postgraduate

22. Please select your gender... O Male O Female

23. Do you have any comments or suggestions regarding travel in the Houston area or about this survey?

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VITA

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